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314 Albert Street,
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The Moisture Content Distribution in Wood used as a Partition between Water and Air.

*By H. D. Roberts.**

Summary.

In the following report is described experimental work carried out to determine the moisture distribution in wood used as a partition between water and air.

The results obtained indicated that, once equilibrium is reached, a very high moisture gradient exists through the thickness of the partition. With stock 2 inches in thickness, the wetted face becomes saturated with water, whereas the moisture content of the dry face becomes stable at a figure approximating the equilibrium moisture content appropriate to the surrounding atmosphere.

1. Introduction.

As far as is known, little information has been published on the comparative moisture absorption and the final moisture equilibrium condition of Australian timbers when used in a form involving the intimate contact of one face with water and the other face with air, a condition existing in some vats, some casks, timbers used in ship construction, and wood pipe.

In the initial fabrication of timber into the forms referred to above, seasoned wood is, for the most part, normally used. There have been some doubts, however, as to the extent to which moisture is subsequently absorbed, the distance to which appreciable penetration of moisture ultimately extends from the wet surface, and the form taken by the moisture distribution in the timber "wall" between the water and the air.

Apart from the general seasoning applications, it is considered that information of this nature will be of assistance in assessing the decay hazard from certain moulds or wood-destroying bacteria in certain forms of construction.

2. Materials Used.

Six timber species were used in the experimental work described hereunder, namely, karri, celery-top pine, blackwood, mountain ash, Douglas fir, and Queensland maple. The material was available in the form of twelve planks (two from each of the above species) each 3 feet long, 5 inches wide, and 3 inches thick, each plank being selected

* An officer of the Seasoning Section, Division of Forests Products.

from a different source so as to obtain as wide a range of material as possible. All planks were machine-dressed to 4 inches in width and 2 inches in thickness so as to exclude any surface checks likely to cause rapid moisture absorption.

From each plank a board 12 inches long was cut. At the same time the moisture distribution through the thickness of this board was obtained by subdividing the thickness into ten equal strips. The moisture content of each strip was then obtained by means of the oven-dry method. The ends of the twelve boards were mitre-cut to an angle of 45°, and then fitted together to form the sides of a wooden container the base of which was made from 7-ply resin-bonded plywood, and the finished overall dimensions of which were 12 in. by 12 in. by 12½ in. Base, edge, and corner joints were glued with a water-resistant adhesive to prevent moisture seepage at these points.

Fig. 1.—Experimental wooden container for moisture absorption tests.

To prevent the breaking away of glue joints due to the swelling of the inner faces of the walls of the container after it was filled with water, it was held in permanent position with adjustable metal clamps as shown in Fig. 1.

The four boards in the top tier of the container were designed as "splash" boards only, i.e., were not included as test samples. The

test samples were thus confined to the centre and bottom tiers of the container. An appreciable alteration in the level of the water in the container, i.e., to the depth of the "splash" boards, could thus occur (from evaporation during week-ends, &c.) without the inner faces of the eight test sample boards being exposed to the air.

All material was in an air dry condition at the commencement of the experiment, the average moisture content varying from 21 per cent. to 11 per cent.

3. Experimental Procedure.

The container was filled with water, none being allowed to spill over the sides, and left in position for approximately thirteen months (from September 1942, until October 1943) in a warm room.*

The water level was maintained throughout the test period. No seepage occurred through joints, and the outer faces of the container were always in a dry condition.

TABLE 1.—MOISTURE DISTRIBUTION THROUGH WOODEN PARTITION WALL OF CONTAINER (2 IN. THICK) HOLDING WATER FOR THIRTEEN MONTHS. MOISTURE DISTRIBUTION SECTIONS EQUALLY SPACED THROUGHOUT THICKNESS OF PARTITION.

Species used in Container.	Number of sections into which thickness of wooden partition was cut. (Numbered from face in contact with water to face in contact with air.)	Moisture distribution through thickness of wooden partition.		Moisture increase or decrease in distribution section after 13 months.	Mean green moisture content of species.
		Before filling container with water, i.e., at commencement of experiment.	*After* one face of the partition had been in contact with water and the other face in contact with air for 13 months.		
		%	%	%	%
Queensland Maple	1	12½	160	+147½	
	2	13	80	+ 67	
	3	14	42	+ 28	
	4	14	37	+ 23	
	5	13½	27	+ 13½	
	6	14	24	+ 10	
	7	13	23	+ 10	
	8	12½	19	+ 6½	
	9	14	16	+ 2	
	10	14	14	+ 0	
Blackwood ..	1	12	124	+112	
	2	12½	118½	+106	
	3	12½	78	+ 65½	
	4	13	31	+ 18	
	5	13	24	+ 11	117
	6	12½	21½	+ 9	
	7	13	18½	+ 5½	
	8	13	16	+ 3	
	9	13	15	+ 2	
	10	13	12½	− ½	

* An average temperature of 68°F. with a relative humidity of 68 per cent. at the time of dismantling the container.

TABLE 1.—*continued.*

Species used in Container.	Number of sections into which thickness of wooden partition was cut. (Numbered from face in contact with water to face in contact with air.)	Moisture distribution through thickness of wooden partition. *Before* filling container with water, i.e., at commencement of experiment.	*After* one face of the partition had been in contact with water and the other face in contact with air for 13 months.	Moisture increase or decrease in distribution section after 13 months.	Mean green moisture content of species.
		%	%	%	%
Celery-top Pine	1	13	110½	+ 97½	
	2	13½	26½	+ 13	
	3	14	22½	+ 8½	
	4	14	20½	+ 6½	
	5	14	18½	+ 4½	130
	6	14	17	+ 3	
	7	14	16½	+ 2½	
	8	14	15½	+ 1½	
	9	14	15	+ 1	
	10	13½	13	− ½	
Mountain Ash	1	12½	100	+ 87½	
	2	12	32	+ 20	
	3	12	25½	+ 13½	
	4	11½	21	+ 9½	
	5	12	19	+ 7	101
	6	12	18½	+ 6½	
	7	12	18½	+ 6½	
	8	12	18½	+ 6½	
	9	11	15½	+ 4½	
	10	10½	13	+ 2½	
Douglas Fir ..	1	20½	81½	+ 61	
	2	21	42½	+ 21½	
	3	21	27½	+ 6½	
	4	21	24	+ 3	Sapwood,
	5	21	23	+ 2	117%
	6	20	21½	+ 1½	Heartwood,
	7	20	21	+ 1	36%
	8	19	20	+ 1	
	9	18	19	+ 1	
	10	15½	14½	− 1	
Karri ..	1	14	73½	+ 59½	%
	2	13½	32½	+ 19	
	3	14	27	+ 13	
	4	14	25½	+ 11½	
	5	14	23	+ 9	
	6	14	21½	+ 7½	68
	7	14½	19	+ 4½	
	8	15	17½	+ 2½	
	9	15	16	+ 1	
	10	14	14½	+ ½	

At the conclusion of the thirteen months, the water was carefully emptied from the container. The latter was then dismantled, and any free moisture on the inner faces of the test samples was removed by drying with an absorbent cloth. Ten moisture distribution sections of

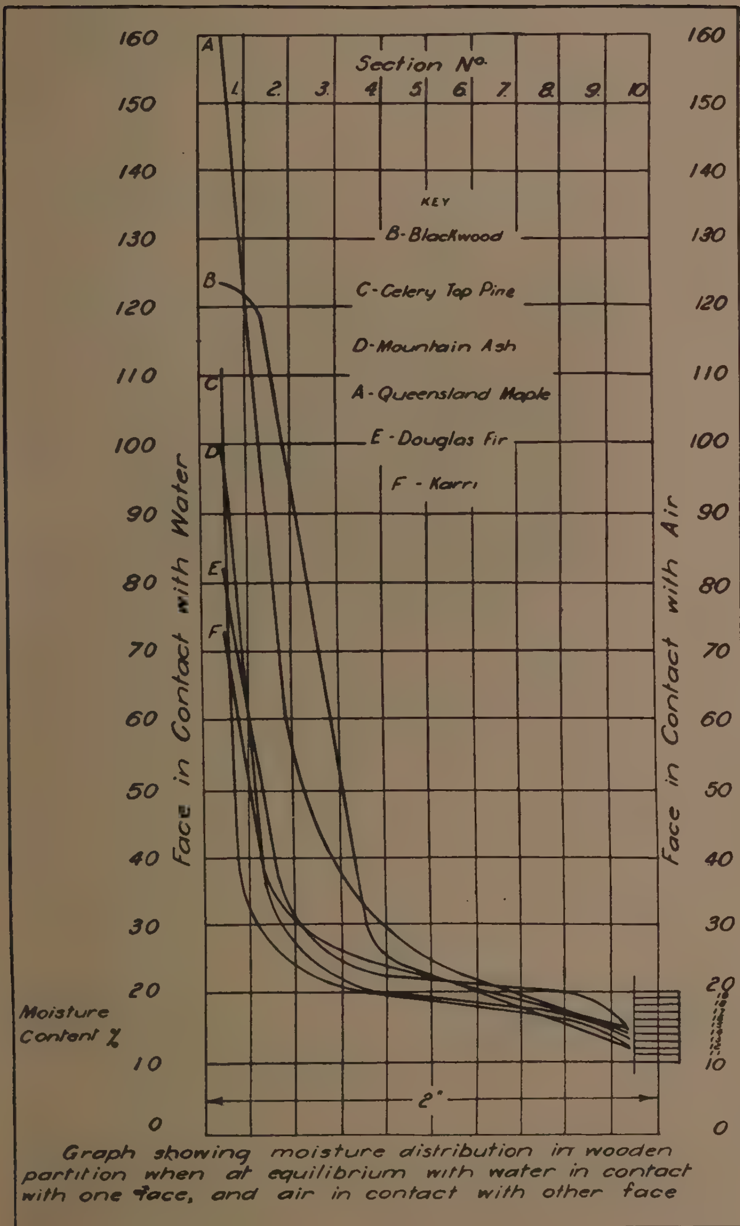

FIG. 2.—Moisture distribution in wood in partition when at equilibrium with one face in contact with water and the other face in contact with air.

equal thickness were then cut from the thickness of each test board, and the moisture content of each strip obtained by means of the oven-dry method.

4. Results and Discussion.

On Table 1 is shown the moisture distribution through the thickness of each plank in the walls of the container under test, both prior to and after completion of the test.

As will be seen, for a depth of approximately $\frac{1}{5}$ in. from the wetted face, the moisture content of the wall of the container reached a very high figure, the results obtained indicating that equilibrium is reached (in this portion of the wall) at about the green moisture content of the species.

As the distance from the wetted face increases, however, the moisture content drops rapidly. For example, $\frac{1}{2}$ in. in from the wetted face, the moisture content was down to approximately fibre saturation point in four of the six species, i.e., celery-top pine, mountain ash, Douglas fir, and karri.

Moisture absorption was much greater in the other two species, i.e., Queensland maple and blackwood, fibre saturation point being reached $\frac{3}{4}$ in. in from the wetted face of wall. In the outer $\frac{1}{5}$ in. of the wall (nearest air) of all six species, the moisture content was down to an average of 14 per cent.

In Fig. 2 the results given in Table 1 are shown in graph form, The relatively steep slope of the moisture content drop, as the distance from the wetted face is increased, is apparent. As previously mentioned, the effect of species on the moisture content of the $\frac{1}{5}$ in. depth nearest the wetted face is pronounced.

A further point of interest is the convergence of most moisture distribution curves at the fibre saturation point.

5. Conclusions.

The results obtained from the experimental work described indicate that when one face of a 2 in. wooden partition is kept continuously wetted, and the other face continuously dry (such as may frequently occur in vats, casks, tanks, wood pipe, ship timbers, &c.), a very high moisture gradient exists across the thickness of the partition once equilibrium is attained.

In the case of the six species tested, the average moisture content of the $\frac{1}{5}$ in. thickness of wood nearest the wetted face tended to reach the average green moisture content of the species, whereas the average moisture content of the $\frac{1}{5}$ in. thickness nearest the dry face (in contact with air) tended towards an average moisture content of about 14 per cent. Furthermore, at a distance of from $\frac{1}{2}$ to $\frac{3}{4}$ in. in from the wetted face, the moisture content tended to reach equilibrium at aproximately the fibre saturation point for the species used.

The Effect of Straw Maturity on the Chemical Composition of Flax Straw and Fibre.

By Jean F. Couchman, B.Sc.

Summary.

During the ripening of flax straw, changes take place in the hemicellulose constituents rendering them more resistant to retting action. As a result, over-mature straw produces harsh, dry, lower grade fibre containing a higher proportion of hemicellulose material.

I. Introduction.

Many factors can affect the spinning quality of flax fibre, one of the most important being the stage of maturity at which the straw is harvested. During 1942, samples of straw from a small-scale time-of-harvest experiment carried out at the Waite Research Institute, S.A., were received at the Division of Forest Products, for retting and fibre evaluation. The flax had been harvested at fourteen weekly intervals starting from the appearance of the first flowers and continuing to the stage at which the plants were dry, brittle and rather harsh. The appearance of the straw at different times of harvest is described in Table 1.

Fibre of the best potential spinning quality was obtained near the middle of the harvest range, viz., at the fifth, sixth, seventh, and eighth harvests, although the fibre yields at these harvests appeared lower than from the later harvested straw. It was noticeable that, as the straw became more mature, the fibre became very dry and harsh in nature. Although retting times showed a tendency to be longer with the later harvests, ret losses were lower in value.

In view of these results it was considered to be of interest to determine the chemical changes which had taken place in the composition of both straw and fibre during the ripening period.

Table 1.—The Appearance of the Straw at each Stage of Maturity.

Harvest No.	*Stage of Growth.*
1	Appearance of first flowers.
3	About middle of flowering period. Some bolls fully formed.
4	Flowering almost complete. Yellowish tinge at base of stems.
5	Flowering complete. About ⅓ plant changed to yellow.
6	Stems changed from green to yellow. Leaves fallen from lower half of stem.
8	Stems light straw colour. Practically all leaves fallen, bolls beginning to rattle.
9	All leaves fallen from stem. Seed becoming firm.
11	Seed fully matured. Straw deep golden shade. Some bolls fallen.
14	Plants dry, rather brittle and harsh. Many bolls fallen and a considerable quantity of seed lost during pulling.

* An officer of the Division of Forest Products.

2. Experimental.

Straw samples from harvest, 1, 5, 8, and 11 were analysed, but, in the case of the fibre, harvest 1 was omitted, because at this stage the straw was not well enough grown to give usable fibre. Subsequently lignin and solvent extractives were determined on four intermediate straw samples (harvest 3, 4, 6, and 9) to confirm whether time of harvest had any effect on these constituents.

The methods of analysis used were identical with those published previously (Couchman, 1939, 1940).

TABLE 2.—SHOWING VARIATION IN THE COMPOSITION OF FLAX STRAW WITH MATURITY.

(*Calculated as percentages on oven-dry weights.*)

——	Harvest.								
	1st.	3rd.	4th.	5th.	6th.	8th.	9th.	11th.	14th.
Ether solubles ..	1·5	1·6	1·5	1·5	1·7	1·6	1·4	1·6	1·3
Benzene alcohol and alcohol solubles ..	5·1	4·7	4·9	5·4	5·9	4·9	4·9	4·6	4·2
Total solvent extractives ..	6·6	6·3	6·4	6·9	7·6	6·5	6·3	6·2	5·5
Soluble in hot water	10·9	..	..	7·9	..	7·4	..	7·0	6·9
Soluble in cold 5·0 per cent. NaOH ..	17·1	..	..	16·8	..	16·5	..	17·2	17·0
Soluble in hot 0·05 per cent. HCl ..	4·3	..	..	3·7	..	3·7	..	3·6	3·5
Soluble in cold 5·0 per cent. NH_4OH	2·1	..	..	1·4	..	1·5	..	1·6	1·4
Total hemicellulose	34·4	..	..	29·8	..	29·1	..	29·4	28·8
Pectin A	1·8	..	..	1·3	..	1·3	..	1·0	0·9
Pectin B	0·4	..	..	0·1	..	0·4	..	0·4	0·4
Pectin C	1·9	..	..	1·6	..	1·4	..	1·8	1·6
Total pectin ..	4·1	..	..	3·0	..	3·1	..	3·2	2·9
Lignin in solvent-extracted sample	15·5	17·6	17·6	17·7	17·7	18·1	18·3	18·3	18·5
Lignin in totally extracted sample	12·4	..	..	14·4	..	15·0	..	15·4	15·1
Pentosan in solvent-extracted sample	16·5	..	..	16·0	..	16·0	..	16·1	16·1
Cellulose (by difference)*	46·6	..	..	48.9	..	49.4	..	49.0	50·6
Ash in original sample	2·3	..	..	1·5	..	1·0	..	1·1	0·8
Ret losses ..	24·5	22·4	21·2	20·2	19·3	15·5	16·2	14·9	11·6
Retting times (hours)	136	112	136	112	184	184	160	160	160
Ratio— $\frac{\text{Ret loss}}{\text{Total hemicellulose}}$	0·71	..	..	0·68	..	0·53	..	0·51	0·41
Yield of fibre ..	13·4	17·7	17·2	19·6	20·7	21·4	21·4	22·1	22·1

* Cellulose figures will also include furfural yielding material usually calculated as "pentosan not in cellulose".

Table 3.—Showing Variation in the Composition of Flax Fibre with Maturity.

(Calculated as percentages on oven-dry weights.)

—	Harvest.			
	5th.	8th.	11th.	14th.
Ether solubles	2·8	2·9	2·7	2·6
Water solubles	2·8	3·7	3·2	4·4
Uronic acids	3·5	4·4	5·2	6·0
Pentosan not in cellulose ..	0·4	1·0	1·0	1·0
Total hemicellulose ..	6·7	9·1	9·4	11·4
Lignin	4·2	3·6	3·5	3·8
Cellulose	86·0	84·9	84·8	84·2
Ash	0·6	0·8	0·8	0·8
Total pentosan	1·6	2·3	2·3	2·4
Pentosan in cellulose ..	1·2	1·2	1·2	1·4
Grade of scutched fibre* ..	F	F	E	D
With further scutching by hand, grade could improve to	K	G	No improvement	No improvement
Grader's remarks	First-class flax	Just beginning to lose quality	Becoming harsher	Very harsh

* Graded by Captain Fullerton just before the analyses were carried out.

Pentosan in Fibre.

To obtain the true pentosan content in the fibre analysis, allowance had to be made for the uronic acid, which also yields furfural on distillation with 12 per cent. hydrochloric acid. Griffioen (1938) stated, from the analyses of A. C. Sloep, that about 3 parts of free galacturonic acid corresponded to 1 part of furfural phloroglucide calculated as pentosan. This agreed approximately with the relation found by Norris and Resch (1935). Pentosan was therefore calculated by subtracting one-third of the percentage of uronic acid from the total percentage pentosan calculated from the furfural yield.

3. Results.

The results are shown in Tables 2 and 3.

4. Examination of Results.

(i) *Solvent-Extractable Material.*

This fraction of the straw consisted of ether, benzene alcohol, and alcohol solubles, and of the fibre, ether solubles only. The benzene alcohol and alcohol solubles of the straw were negatively correlated, so the variation in the sum of these two fractions only was considered. For the fibre there was a slight tendency to a decrease with the more mature samples, and for the straw a maximum was recorded at the 6th harvest. The evidence available, however, was insufficient to prove any trends.

(ii) *Total Hemicellulose.*

A marked decrease occurred in the hemicellulose content of the straw from the 1st to the 5th harvests, but with the later harvests very little further variation occurred. A similar effect was observed for each constituent of the hemicellulose fraction. It would be expected that this fraction would incur the greater proportion of the ret loss. In a preliminary examination of the losses due to retting (Couchman, 1939) 68 per cent. of the total ret loss was incurred by the hemicellulose. During the retting of these straw samples, ret loss decreased from 24·5 per cent. at the 1st harvest to 11·6 per cent. at the 14th harvest. The ratio of ret loss to hemicellulose is shown in Table 2 to decrease from 0·71 at the 1st harvest to 0·41 at the 14th harvest. Thus the proportion of this material lost during the retting evidently decreased with the ripening of the straw. As all straw received similar retting treatment, it can be assumed that the hemicellulose present in the straw at the later harvests was more resistant to retting action than that in the earlier harvested samples. This was borne out by the fact that retting times tended to be longer, although ret losses were smaller at the later harvests. In other words, the straw was more difficult to ret. Some polymerization of the constituents may have taken place.

In the case of the fibre a consistent increase in hemicellulose content occurred with the ripening of the straw. This result confirmed the theory that as the straw ripened the hemicellulose material underwent a change which made it resistant to retting and caused it to be retained to a certain extent by the fibre. This may partly account for the higher fibre yields from the later harvests. Considering each constituent of the hemicellulose of the fibre separately, water solubles and pentosans increased from the 5th to the 8th harvest only, but a consistent increase in uronic acid content occurred from the 5th to the 14th harvest.

(iii) *Pectin.*

The total pectin content of the straw decreased by 1·1 per cent. from the 1st to the 5th harvest, but from the 5th to the 14th harvest very little further variation occurred. It was expected that variations in pectin content would be more marked. These substances are usually found in large amounts as constituents of young and green plant tissues, but in mature plants they are rarely present in any quantity. Apparently at the 5th harvest stage the plants had reached a state of maturity at which the pectin content of the straw had attained its minimum.

(iv) *Lignin.*

The lignin content of the straw increased with time of harvest, the greatest increase occurring from the 1st to the 3rd harvest. Further increases were small and gradual.

It was expected from these results that the percentage lignin in the fibre would also increase with straw maturity, thus partly accounting for the increased harshness and decrease in grade with the later harvests. This, however, was not so, the lignin content of the fibre being highest at the 5th harvest. It appeared, therefore, that as the straw matured a decrease in the lignin content of the fibre occurred. It is probable, on the other hand, that the actual lignin content of the

fibre remained stationary, and the association of more hemicellulose with the fibre took place during ripening, thus causing an apparent decrease in lignin content.

(v) *Cellulose.*

Cellulose determinations were not made on the straw, because previous analyses (Couchman, 1939, 1940) had indicated that figures estimated by difference would be sufficiently accurate for comparative purposes, and whatever differences were found in lignin, hemicellulose, &c., would be reflected in the cellulose figures.

Determinations made on the fibre showed that the decrease in cellulose was most marked from the 5th to the 8th harvest. There was only a slight tendency for a further decrease to occur with maturity. It is likely that the cellulose behaved in a manner similar to the lignin, remaining constant throughout this harvest range, an apparent decrease being caused by increase of hemicellulose material.

(vi) *Ash.*

The percentage ash in the straw decreased from 2·3 at harvest 1 to 0·8 at harvest 14, whereas in the fibre from harvest 5 to harvest 14, an increase from 0·6 to 0·8 per cent. was recorded. This suggested that either some redistribution of the inorganic constituents had taken place or their character had changed to a more insoluble type during ripening.

5. Conclusions.

With both straw and fibre the most marked changes in all constituents occurred near the beginning of the range examined, viz., from the 1st to the 5th harvest for the straw, and from the 5th to 8th harvest for the fibre. Subsequent changes in the majority of the constituents were small and gradual.

Evidence was found of the modification of the hemicellulose constituents of the straw during ripening into a more resistant type (probably by polymerization), causing an increase in the hemicellulose content of the fibre. Longer retting times, lower ret losses, and harsher fibre of lower grade with the later harvests can also be accounted for by this change during the maturing period.

Increase in the hemicellulose content of the fibre was due with the later harvests to a consistent increase in uronic acid content. It is therefore suggested that, as well as being the chief cause of decrease in fibre quality owing to increase in straw maturity, uronic acid content may be useful, with other factors, in the assessment of fibre grade.

6. Acknowledgments.

Grateful acknowledgment is made to Messrs. A. G. Charles and J. Sterling for assisting with the chemical analyses, and to Dr. W. E. Cohen for helpful advice.

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Double-compartment Pot Cultures for Studies in Plant Nutrition.

*By A. J. Anderson, B.Sc.(Agric.)**

Summary.

The use of double-compartment pot cultures for the investigation of certain problems in plant nutrition is examined and discussed.

The equipment described enables plants to be grown in a soil and at the same time obtain some of their nutrients from a water culture. In this way direct contact between an added nutrient and the soil can be avoided; and the effect of nutrients provided in a culture solution can be compared with the effect of the same nutrients added to the soil.

An automatic irrigator is used to maintain the moisture level in the soil. The method is particularly suitable for studies with legumes. The roots of these plants can nodulate normally in the soil in an upper compartment, and grow into a solution beneath.

Within the range of treatments employed, roots developed only in solutions containing calcium sulphate. The concentrations employed were 1·376 and 0·344 grams of $CaSO_4 2H_2O$ per litre. Plants did not respond to phosphate in solutions from which calcium sulphate was omitted.

1. Introduction.

Certain problems in plant nutrition have been studied by growing plants in double-compartment pots, so that the roots are able to develop in each compartment. In this way it is possible to apply different nutrient treatments to sections of the root system of a single plant at the concentrations employed in sand and water cultures. As the method can be used to provide the plant with nutrients in one compartment without direct contact between the added nutrient and soil in a second compartment, the purpose of the method is in some respects similar to that of plant injection described most fully by Roach (1938). The value of injection methods for avoiding effects of the soil on the availability of an added nutrient, and of treatment on the availability of nutrients already in the soil, was pointed out by Collison, Harlan, and Sweeney (1932) and by Roach (1931).

Frank (1893) supported plants directly above the junction of two vessels which were each filled with the same soil. He added calcium nitrate to one of the compartments of each pair, and in this way studied its effect on root development. Similarly, Partridge (1938) applied different treatments to each half of the root system of a tree, and studied the cross-transfer of water and nutrients by observing the effects on the corresponding sections of the foliage. Riceman and Donald (1938), in a study of the effect of a calcareous soil on the availability of added phosphate, grew plants of subterranean clover with their roots partly in a sand culture lacking phosphate, and partly

* An officer of the Council stationed at the Waite Agricultural Research Institute, University of Adelaide.

in a medium in which phosphate was provided. This medium was varied in steps from a pure calcareous sand to a pure river sand. A tumbler containing the medium supplied with phosphate was buried in the sand in a pot, and seeds were planted immediately above the rim of the tumbler. They found that normal development occurred only when the tap root entered the tumbler. In a similar study, the author has used a modification of the method described by Frank (1893) which has the advantage that the growth media can be completely separated, but the disadvantage that the tap root must be confined to one compartment. For this reason oats were employed. Soil was used in one compartment and pure quartz sand containing the nutrients to be tested in the other; transplanted oat seedlings were supported by a structure fitted above the junction of the jars as illustrated in Fig. 1.

In subsequent investigations of this nature, a new method has been employed. This can be used for all plants and is described in detail below.

2. Method.

In this method, illustrated in Fig 2 and Plate 1, one compartment with a floor through which plant roots could penetrate was situated directly above a second compartment. Soil, equipped with an automatic irrigator (Anderson, 1944) was placed in the top compartment; the lower compartment contained a water-culture solution. Roots developed in the soil and also normally in the humid air between the two compartments.

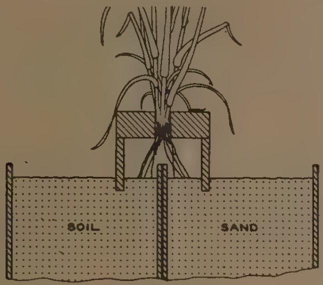

Fig. 1.—A method used for providing oats with nutrients in sand and soil.

A unit is shown in cross-section in Fig. 2. Details are as follows:—The frame (A) of the top compartment is supported by flanges (B) in the top of a rectangular glass jar (C). It fits loosely to allow glass tubing to be inserted between the frame and the battery jar at the corners for maintaining the level of the solution. The lower flange (D) supports a $\frac{1}{4}$-inch mesh wire grid (E). A layer of glass wool (F) on this supports the soil, and allows plant roots to penetrate to the solution. During growth each jar is covered with black-surfaced paper to exclude light. Paper clips are used to keep the paper covering in position, and facilitate inspection of the roots in the solution below.

Frames made of black iron were dipped in tin, and subsequently coated with clear Dulux and baked at 120°C. These materials have been found satisfactory for the purposes for which they have been used.

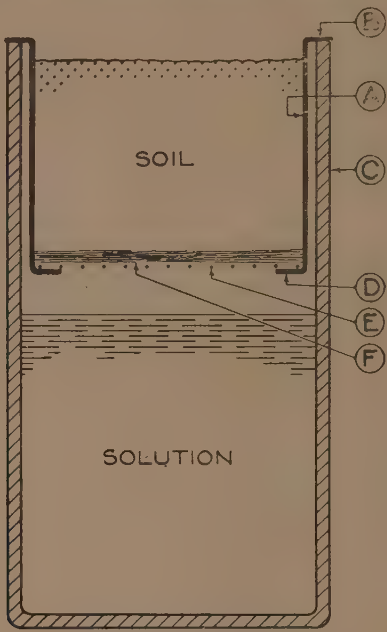

Fig. 2.—Method of supporting soil in a compartment through which roots can develop into a solution below.

3. Experimental.

The method was employed in (*a*) preliminary tests to investigate the effect of composition of the nutrient solution on root growth, and (*b*) an experiment to compare the effects of phosphate added to the soil and to the solution.

Preliminary Tests.—It was found that movement of water through the soil into the compartment below could be prevented by careful control of the soil moisture content. Plant roots grew through the soil to the surface of the water in a few days, but penetrated only a few millimetres into distilled water. The roots also did not grow in solutions of sodium, potassium, or magnesium sulphate with osmotic pressures of approximately 0·4 atmospheres, nor in a solution of monocalcium phosphate containing 126 mg. of $Ca(H_2PO_4)_2H_2O$ per litre. They grew, however, in a solution of calcium sulphate containing 1,376 mg. $CaSO_42H_2O$ per litre and also in solution 5 (*vide* footnote, Table 1), lacking nitrogen, and solution 4 (*vide* footnote, Table 1) lacking phosphate and nitrogen, both of which included 344 mg. of $CaSO_42H_2O$ per litre (Plate 1 and Table 1). The highest yields in the following experiment were obtained with phosphate, supplied in

the solution either with calcium sulphate or a mixture of nutrients including calcium sulphate, indicating that the supply of phosphate for all other treatments was below optimum.

Test of the Method with Phosphate.—Using lucerne as a test plant, the effect of phosphate added to the soil was compared with that of phosphate in solution provided separately in the lower compartment. One of the soils employed was a podsol in which the availability of phosphate had previously been studied in the field (Trumble and Donald, 1938). The other was a washed river sand to which a basal dressing of all nutrients except nitrogen and phosphate was applied. The maximum soil moisture tension, as controlled by the automatic irrigator, was 25 millimetres of mercury for the sand, and 140 millimetres of mercury for the soil. After an irrigation of 100 ml. of water, the tension of both, as measured by the manometer, fell to about 10 mm. of mercury. This corresponded to a maximum water content of 11 per cent. for the sand and 18·6 per cent. for the soil. These were equivalent to 44 and 55 per cent. of the respective water holding capacities. As 1·40 kg. of sand and 1·46 kg. of soil were used, the maximum water contents were 160 ml. for the sand and 260 ml. for the soil.

All treatments, details of which are appended to Table 1, were conducted in duplicate. Phosphate treatments in this experiment were applied four weeks after sowing to allow time for roots to develop in both the soil and the solution below. Treatments in the solution were based on concentrations recommended for water cultures by Hoagland and Arnon (1938). All plants were harvested eleven weeks after sowing.

The results of the experiment are summarized in Table 1 and Fig. 3. All yields were multiplied by 10^2 and transformed to logarithms for purposes of analysis. The means of the logarithms for the various treatments employed are given in Table 1. The antilogarithms of these divided by 10^2 give the geometric means of the original yields. These were tested and found to be very close to the arithmetic means. An increase in one unit in the logarithm mean would, of course, represent a tenfold increase in the yield mean. The ratio of the yield means can be obtained simply by reference to a table of logarithms. For example, an increase of 0·301 in the log. mean indicates that the yield mean was doubled.

The lucerne was inoculated with an effective strain of *Rhizobium,* and no combined nitrogen was added to the cultures. Nodules did not occur on the roots in any of the solutions, but all plants were well nodulated, both in the sand and the soil in the upper compartments.

4. Discussion.

The effect of the phosphate dressing on the soil was much greater than the effect of an equal dressing of phosphate on the river sand. The difference is illustrated in Plate 2 and was highly significant. If the effect of the phosphate in the solution were disregarded, this difference would give no indication as to the nature of the deficiency in the sand; and the poor response to phosphate in the sand might be interpreted as indicating another limiting factor. The response to the phosphate in the solution, however, clearly indicates an extreme phosphate deficiency.

Table 1.—Comparison of Effects of Nutrients Provided in the Soils and in the Solutions.

Treatment.		Log.$_{10}$ of Oven-Dry Yield per Pot in g. x 10^2.					Ratio of Roots in Solution to Total Roots.	Ratio of Total Roots to Total Yield (Root Weight Ratio).
Nutrients Added to the Soil.	Nutrients in the Solution.	Tops.	Roots in Soil.	Roots in Solution.	Total Roots.	Total Plants.		
(S_1) *River Sand.*								
Nil	Nil	0·700	1·167	Absent	1·167	1·296	Nil	0·745
P_1	Nil	0·780	1·203	Absent	1·203	1·342	Nil	0·728
Nil	P_2 + Ca	1·975	1·778	1·241	1·891	2·236	0·227	0·452
Nil	Ca	0·700	1·000	0·000	1·041	1·204	0·091	0·688
Nil	P_2	0·825	1·127	Absent	1·127	1·303	Nil	0·667
Nil	Bas.	0·630	1·016	0·000	1·057	1·196	0·088	0·728
P_1	Bas.	0·825	1·191	0·588	1·288	1·417	0·200	0·744
Nil	P_2 + Bas.	2·155	2·162	1·102	2·202	2·482	0·088	0·526
(S_2) *Podsol.*								
Nil	Nil	1·595	1·717	Absent	1·717	1·961	Nil	0·569
P_1	Nil	2·025	2·113	Absent	2·113	2·374	Nil	0·550
Nil	P_2 + Ca	2·215	1·977	1·430	2·086	2·457	0·221	0·425
Nil	Bas.	1·670	1·707	0·997	1·785	2·181	0·164	0·565
P_1	Bas.	2·135	2·064	1·627	2·200	2·469	0·269	0·540
Nil	P_2 + Bas.	2·415	2·273	1·358	2·333	2·678	0·125	0·428
Standard Error ..		0·070	0·096	0·078 Nils omitted in analysis	0·084	0·087	0·0363 Nils omitted in analysis	0·0233
Sig. dif. for P = 0·05		0·216	0·296	0·270	0·259	0·268	0·126	0·072
Sig. dif. for P = 0·01		0·301	0·415	0·409	0·363	0·376	0·191	0·101
Interactions sig. at 0·01		S x P	S x P	S x P	S x P	S x P		S x P

Soil Treatment.

P_1 = 37·8 mg. of $Ca(H_2PO_4)_2H_2O$ per pot, based on a phosphate dressing equivalent to 56 lb. per acre of superphosphate on the pot surface.

Treatments in Solutions. (1·75 l. of solution was used in the lower compartment.)

Solution 1. P_2 = 126·1 mg. of $Ca(H_2PO_4)_2H_2O$ per litre.

Solution 2. Ca = 1376·0 mg. of $CaSO_42H_2O$ per litre.

Solution 3. P_2 + Ca = 126·1 mg. of $Ca(H_2PO_4)_2H_2O$ + 1376·0 mg. of $CaSO_42H_2O$ per litre.

Solution 4. Bas = a nutrient solution lacking phosphate and nitrogen, containing the following amounts of salts per litre: K_2SO_4 — 435 mg.; $MgSO_47H_2O$ — 493 mg.; $CaSO_42H_2O$ — 344 mg.; $MnSO_44H_2O$ — 2·04 mg.; $ZnSO_47H_2O$ — 0·22 mg.; $CuSO_45H_2O$ — 0·08 mg.; $Na_2MoO_4H_2O$ — 0·09 mg.; H_3BO_3 — 2·86 mg.; $FeSO_47H_2O$ — 5·0 mg.

Solution 5. P_2 + Bas = a nutrient solution lacking nitrogen only, containing amounts of salts per litre as for solutions 1 and 4.

Soils.

S_1 = River sand.
S_2 = Podsolised soil.

The same amount of phosphate on the podsol increased the yield about half as much as did the phosphate in the solution. It is interesting to compare this with the effect of phosphate on the yield of a mixed pasture on the same soil in the field. Trumble and Donald (1938), expressing x in cwt. of superphosphate per acre, fitted the Mitscherlich expression $y = A\ (1\text{–}10^{-cx})$ (Stewart, 1932) to their yield data, and obtained values for the effect factor c ranging from 0·30 to 0·47. From this it can be calculated that the effect of $\frac{1}{2}$ cwt. per acre of superphosphate in the field would have been expected to be between 29 per cent. and 42 per cent. of the maximum increase obtainable with superphosphate, or rather less than the value of approximately 50 per cent. obtained in the pot cultures.

The increase in yield due to phosphate in the solution was accompanied by a marked reduction in the ratio of roots to total plant (Table 1). This is consistent with the results obtained by other workers on the effects of phosphate on root weight ratios (Williams, 1936). Root weight ratios for the very deficient washed river sand were greater than for the podsol, and the decrease in the ratio due to phosphate in the solution was also greater for the sand series.

The effect of phosphate in the solution on the root weight ratios was not dependent on its effect on the relative development of roots in the two compartments. The ratio of roots in the solution to total roots ranged from 0·088 to 0·269 for the various treatments where calcium sulphate was present in the solution. It was increased by adding calcium phosphate to the calcium sulphate solution, but was not increased by adding calcium phosphate to solution 4 (Table 1). Where solution 4 was employed, the ratio was increased when phosphate was applied to the soil. It is of further interest to note that the only evidence of a reduction in yield due to treatments which increased the relative root development in the phosphate free solution, was a slight but insignificant effect on plants receiving no phosphate on the river sand.

During growth, from seven weeks after sowing until harvest, weekly records of the heights of plants were kept for each treatment. Graphs of heights for treatments with solution 4 below are given in Fig. 3 for both the sand and podsol.

The graphs demonstrate the effects of the continuous supply of phosphate in the solutions. The difference between the height of plants receiving phosphate in the solution and those untreated or receiving phosphate in the soil increased continuously up to the harvest period. The graphs in Fig. 3 show that during the period of measurement there was no increase in the height of lucerne where phosphate was added to the river sand, although marked increases were recorded where phosphate was added to the podsol or to the solutions used in conjunction with either soil. The results demonstrate the value of the method as a means of avoiding contact between an added nutrient and the soil.

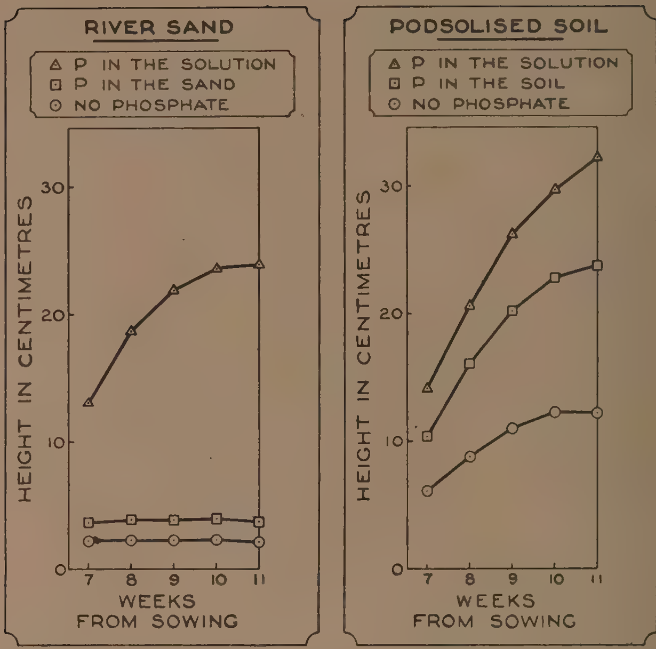

FIG. 3.—Graphs of heights of lucerne with solution 4. Phosphate treatments were applied four weeks after sowing.

5. Acknowledgment.

Thanks are due to Mr. E. J. Leaney, of the Waite Institute, who prepared the diagrams for publication.

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An Automatic Irrigator Actuated by a Soil-Moisture Tensiometer.

*By A. J. Anderson, B.Sc.(Agric.)**

Summary.

The automatic irrigator described in this paper delivers a known volume of water each time the soil moisture tension reaches a predetermined maximum value, as measured by a tensiometer. It has been used in pot experiments in which plants were grown with their roots partly in a soil and partly in a nutrient medium in a second compartment.

1. Earlier Methods.

Many auto-irrigators have been described previously. For sand cultures, these include equipment which provides automatic irrigation at hourly or other selected intervals (Eaton, 1936, 1941; Chapman and Liebig, 1938; Gauch and Wadleigh, 1943). In each case the excess solution delivered to a sand culture returns through a drain tube to a reservoir.

For pots without drainage, methods have been developed (Johnston and Atkins, 1939; Steinberg, 1930) for providing automatic irrigation when the weight of the pot falls to a pre-determined level.

Where drainage cannot be provided, and where weighing of pots is impracticable, soil moisture tension provides a particularly useful basis for the irrigation of pot cultures. Methods based on the principle of supplying water to the soil continuously under tension have frequently been described by various workers (Livingston, 1908, 1918; Richards, 1928; Richards and Blood, 1934; Richards and Loomis, 1942; Calfee and McHargue, 1937). Hendrickson and Veihmeyer (1931) found in their experiments using the method described by Livingston (1918) that moisture and plant roots concentrated around the porous clay auto-irrigator. Richards and Loomis (1942) found with an improved method that the soil moisture, under crop plants with high transpiration rates and a rapidly developing root system, could not be maintained at any constant value except near saturation. This criticism is equally applicable to other methods of supplying water continuously under tension.

By using a porous cup buried in the soil, after the manner described by Livingston (1908) for his auto-irrigator, a measure of the capillary tension in the soil can be obtained, by connecting the water column with a mercury manometer (Richards, 1928).

Richards and Gardner (1936) have suggested the term "tensiometer" for the apparatus. Tensiometers have been designed for use both in the field and for pot cultures (Rogers, 1935, Staebner, 1939; Richards, 1942; Heath, 1929; Richards and Pearson, 1939; Stoeckeler and Aamodt, 1940). Both Heath (1929) and Richards and Pearson (1939) reported satisfactory results, particularly for intermediate moisture levels, using tensiometers for determining the amount of water required to be added to pot cultures.

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* An officer of the Council stationed at the Waite Agricultural Research Institute, University of Adelaide.

The capillary tension of the soil water is of particular value as an index of the force with which the soil water is withheld from the plant.

Post (1941) used a tensiometer for controlling an automatic watering device for experimental plots, water being injected into the plots through underground tiles at intervals as required.

2. Principles Followed.

A general view of the auto-irrigator described in this paper is shown in Plate 3. The aspirator provides a main supply of water. The double row of inverted bottles along the top fill slowly to a constant level from the aspirator. When the moisture content of the soil in a pot falls to a pre-determined minimum, water automatically siphons from the corresponding bottle on to the soil. The minimum moisture content is controlled by a tensiometer, with a mercury manometer. The volume of water delivered at each irrigation is sufficient to wet the soil uniformly to a desired level.

The pot culture in the foreground with the paper covering removed, indicates the particular purpose for which the auto-irrigator is used. The moisture content of the soil in the top compartment is maintained by the auto-irrigator, while the plant roots are able to develop in the culture solution below.

The principle of the auto-irrigator is represented diagramatically in Fig. 1.

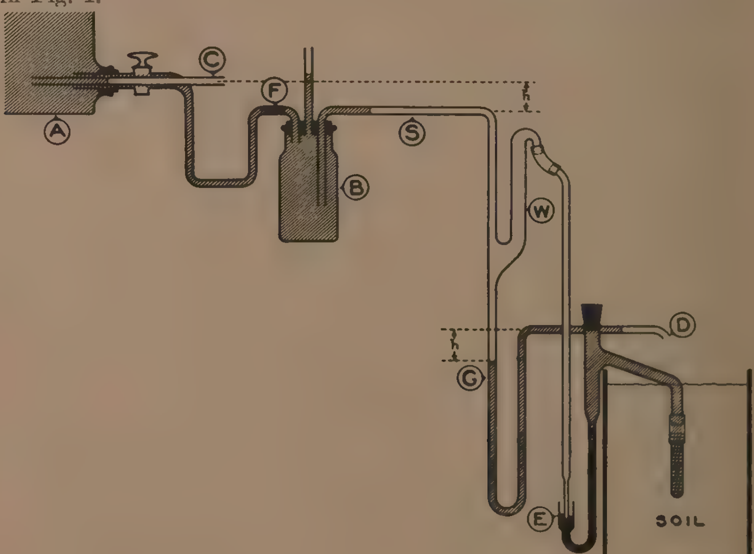

FIG. 1.—Diagram illustrating the principle of the automatic irrigator.

A large capacity aspirator (A) (Fig. 1) which maintains a constant head, is connected by a pipe line to a series of bottles, one of which (B) is required for each soil to be irrigated. The light shading represents the position of water as it occurs in the tubes between irrigations. The bottle (B) is charged with water, while the soil water tension is such that mercury in the open arm of the manometer closes the tip

of the control tube (E). Under these conditions the pressure of the air in the closed system (W) is greater than atmospheric pressure by an amount equal to the head of water (h) above the siphon tube. The head (h) above the siphon tube is balanced by a head of water (h) in the loop (G).

When the soil water tension increases sufficiently ,to cause the mercury to move below the tip of the control tube (E), the fall in the air pressure in the system (W) allows water from the bottle (B) to siphon on to the soil at (D). The increase in the moisture content of the soil then causes the mercury to close the control tube. The bottle (B) fills slowly again to a constant level through the capillary tube (F) from the main water supply (A) and remains full until another irrigation is necessary.

A horizontal tube (C), in place of the vertical tube commonly used in a Mariotte bottle, maintains a fairly constant head with changing temperature in the glasshouse. A horizonal tube (S), of sufficient capacity, prevents falling temperature from increasing the head at the top of the siphon column.

3. Details of Construction.

Other specifications are given in a description of the unit shown in Fig. 2.

This unit embodies the principles set out above and represented diagrammatically in Fig. 1, and has been used for maintaining the moisture content of soils in pots about 20 cm. high with a capacity of approximately 3 litres.

The capillary tube (H) (Fig. 2) of the tensiometer must be sufficiently large in relation to the open arm (I) of the manometer to provide sensitivity. The open end of the mercury must be dry and clean.

The large bowl (J) prevents mercury from passing over to the porous tube (M) when the tensiometer is allowed to dry out. The rubber stopper (K) provides a simple means of removing air and filling with water. The arm (L) is sufficiently large and sloped to allow upward movement of air bubbles. The porous tube (M) attached to the arm (L) must be sufficiently permeable to allow mercury to return after watering before the bottle (B) has filled sufficiently to siphon a second time. Tubes of suitable permeability were made according to the method described by Marshall (1941)*. A rapid fall will not affect the completion of a siphon that has begun. The unit rests conveniently over the side of the pot, with the porous tube buried in the soil. Tensions required for good growth with all the soils used were within the range of 15 cm. of mercury developed by the unit described.

* The following description of the essential features of the method is given, since Dr. Marshall's paper is not generally available to readers.

The tubes were made of commercial ceramic clay, made up into a suspension of 250 g. of clay in 1 litre of water. This suspension was drawn up into a 7 mm. bore through a plaster of paris cylinder 10 cm. long, and about 3 ml. of water was allowed to soak into the plaster. Care was taken to avoid air bubbles, and this process was repeated four times. The resultant clay tube was tapped out of the cast when dry. One end of each tube was then remoistened and closed with the fingers. After redrying, the tubes were placed in a cool electric furnace and heated gradually to a temperature of 1,100°C., which was maintained for three hours. The baked tubes were tested for suitable permeability and ability to withstand tensions of nearly one atmosphere without leaking air.

A short length of capillary tubing (F) restricts the rate of flow of water from the main water supply outlet (N) through the inlet tube (P) to the bottle (B). The capillary reduces the rate at which the reservoir fills, and also maintains the level in one bottle when that in another bottle has fallen.

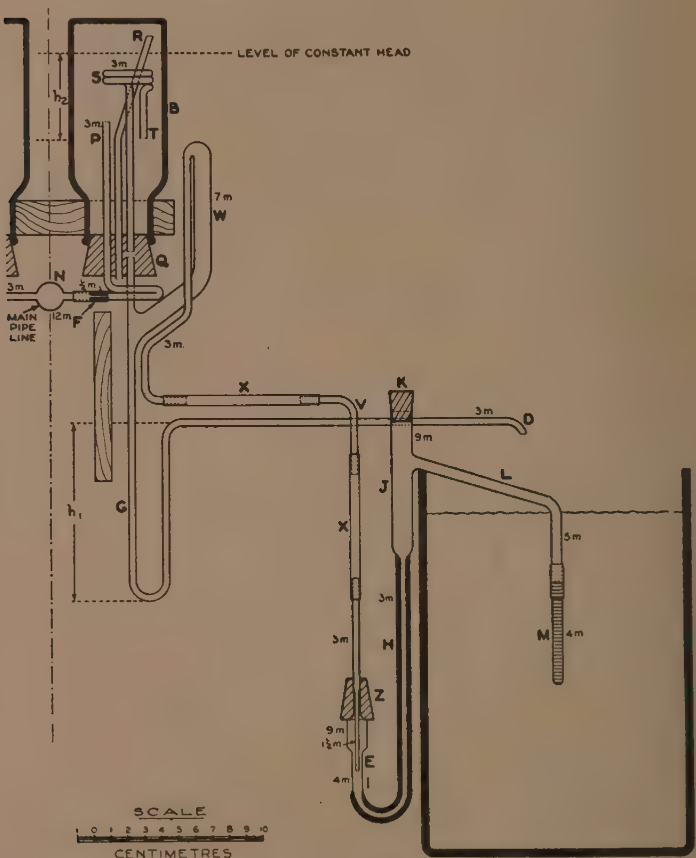

FIG. 2.—Scale drawing of a watering unit. Numerals indicate internal diameters in millimetres.

Three holes are bored through each rubber stopper (Q). One takes the water inlet (P), and another a tube (R) which maintains atmospheric pressure on the surface of the water in the bottle. The top of this must be so placed that it does not collect drips of condensed water which collect in the top of the bottle. The upper half of the third hole carries the siphon tube (S). The top part of the siphon tube is turned into a horizontal spiral to control the effect of temperature on the pressure in the siphon system. This prevents siphoning due to falling temperature in the same way as the long arm (S) shown in

Fig. 1. In order that the siphon tube may empty cleanly after siphoning, the bore must be small, and the lower end of the tube (T) must be clear of other glass surfaces. The length of the tube (T) determines the amount siphoned.

The unit which consists both of the water delivery tube (D) and the control tube (V) is supported in the lower half of the third hole in the stopper, directly below the siphon tube (S). The tip of the water delivery tube is bent down slightly to allow water flowing on the soil to run clear of the tubing.

The loop (G) remains filled with water after siphoning is complete. The height (h_1) of the loop must be greater than the height (h_2) in the bottle above, in order to balance safely the maximum pressure developed above when the temperature rises.

The water trap (W) must be sufficiently high to prevent water passing over to the control tube (V), and large enough to allow water to run back into the water delivery tube when the tip of the control tube (E) is closed by mercury. The flexible joints (X) must be well sealed to the glass. They allow the height of the tip of the control tube to be easily adjusted, and kept in position by means of the cork (Z).

Rubber tubing, which was used for connecting the glass tubing, perished rapidly under glass-house conditions, and required frequent replacement. Flexible tubing of certain synthetic materials which will withstand the conditions is available. Gauch and Wadleigh (1943) have recommended the use of windshield wiper hose for a similar purpose. Richards and Pearson (1939) used Koroseal tubing in the construction of tensiometers. Nylex insulation tubing sealed to the glass with dulux has been used successfully.

Two auto-irrigators similar to that shown in Plate 3 were constructed in 1940, and have satisfactorily maintained the moisture content of soils in a number of trials, in one case involving a total of 72 pot cultures. Plants watered entirely by the auto-irrigator have grown well, both in sand cultures and in heavy soils. With soils which do not shrink from the sides of the container, the moisture content has been maintained at a level low enough to prevent any movement of water through free drainage holes at the bottom, but sufficient for good growth.

4. Acknowledgments.

It is a pleasure to acknowledge the assistance and many valuable suggestions of Dr. T. J. Marshall, Soil Physics Section, Division of Soils, Council for Scientific and Industrial Research.

The author also wishes to acknowledge the help of Mr. V. A. Stephen, of the Waite Institute, who constructed the most difficult glass units, and of Mr. E. J. Leaney, of the Waite Institute, who prepared the diagrams for publication.

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Tests on the Holding Power of Titan Plain and Processed Cement-coated Nails.

*By N. H. Kloat, B.Sc.**

Summary.

Tests have been conducted on the holding power of Titan plain and processed cement-coated nails under static and impact loads. Agreement between immediate and delayed tests as regards the relative efficiency of the nails was obtained, indicating that the processed cement-coated nail has an efficiency about 50 per cent. greater than plain nails now being made.

1. Introduction.

At the request of the Army Design Directorate, a series of tests was carried out to compare the holding power of a new processed cement-coated nail with the standard plain nail. Although manufacturers have in the past claimed superiority for the cement-coated nail, tests by this laboratory have failed to substantiate the claim.†

* An officer of the Division of Forest Products.

† Langlands, I. (1933).—The Holding Power of Special Nails. Coun. Sci. Ind. Res. (Aust.) Pamph. No. 46.

Both types of nail were subjected to a standard testing procedure in which both the static and impact holding power of the nails were measured immediately after driving into wooden blocks and also three months after driving. Subsidiary tests were also conducted on plain, cement-coated, and processed nails left over from previous experimental work on this subject.

Western hemlock (*Tsuga heterophylla*), which was almost exclusively used in previous nail pulling tests, was replaced in this series by bunya pine (*Araucaria bidwillii*), previous tests having shown that there is no significant difference in the relative holding power of different types of nail between hemlock and hoop pine (*Araucaria cunninghamii*) to which bunya pine is closely allied.

2. Description of Materials.

(*a*) *Nails.*—(1) $2\frac{1}{4}$ in. x 12 gauge F.H. Titan plain nail, diam. 0·103 in.
(2) $2\frac{1}{4}$ in. x 12 gauge F.H. Titan processed cement-coated nail, diam 0·103 in.
} new stock.

(3) $2\frac{1}{4}$ in. x 12 gauge F.H. Titan plain nail, diam. 0·103 in.
(4) $2\frac{1}{4}$ in. x 12 gauge F.H. Titan cement-coated nail, diam. 0·103 in.
(5) $2\frac{1}{4}$ in. x 12 gauge F.H. Titan processed nail, diam. 0·103 in.
} old stock.

Nails Nos. 3 and 5 were from stock manufactured about six to seven years ago, No. 4 being probably about ten years old.

(*b*) *Timber.*—From each of ten flitches of bunya pine, six end-matched specimens were cut and machined to 6 in. x 2 in. x 2 in. The flitches were selected to give as wide a range as possible. In the following table, the average density of each flitch as determined from four of the six specimens, is listed:—

Flitch No.	*Av. Density.**	*Flitch No.*	*Av. Density.**
	lb./cu.ft.		lb./cu. ft.
1 ..	28·6	6 ..	29·6
2 ..	25·7	7 ..	28·9
3 ..	28·4	8 ..	32·8
4 ..	33·2	9 ..	25·2
5 ..	32·2	10 ..	26·6

* Weight/volume at test.

The variation of density within each flitch was small, with the exception of flitch 9, where the maximum difference was 2·4 lb./cu. ft.

3. Technique.

Each nail was marked with a file $1\frac{3}{4}$ in. from the point and driven by hand up to this mark. Two blocks from each flitch were nailed in the following manner:—

One plain nail (new) and one processed cement-coated nail were driven by hand into the opposite ends, one of each into the radial face

$1\frac{3}{4}$ in. from each end and one each into the tangential face $2\frac{1}{4}$ in. from each end. This procedure made certain that none of the nails fouled each other.

The nails in one set of blocks, i.e., ten specimens—60 nails, were withdrawn in a Southwark-Emery 20,000 lb. Universal testing machine at a rate of 75 lb./min. and the maximum load required to draw each nail recorded. The second set was subjected to test in a Denison toughness machine to which a special fitting for nail pulling was attached, the work done in pulling the nails under impact being recorded in this case.

A further two blocks from each flitch were nailed up as described above and set aside for testing after three months (hereafter referred to as "delayed" tests).

Finally, the last two sets of blocks were utilized for comparing firstly the new plain nail with the old, one of each being driven into the side grain of one set; secondly for comparing the old plain nail (No. 3) with the processed nail (No. 5), one of each being driven into the end grain, and one side grain face of the remaining specimens; and thirdly for comparing the old plain nail (No. 3) with the cement-coated (No. 4), one of each being driven into the remaining side grain face of each of the specimens. The nails in these subsidiary tests were withdrawn in the S.E. 20,000 lb. testing machine, i.e., statically, under the same conditions as the first main set.

After test, moisture determinations were made on each block by oven drying.

4. Results.

The average moisture content of the blocks used in the immediate tests was 12 per cent.; in the delayed tests 10 per cent. In Table 1 the average values obtained for each condition of test on the new plain and processed cement-coated nails are given.

TABLE 1.

Condition of Test.	Plain Nail (No. 1).			Processed Cement-Coated Nail (No. 2).		
	Radial Face.	Tangential Face.	End.	Radial Face.	Tangential Face.	End.
Immediate Tests.						
Static (lb.)	133	118	98	251	226	173
Impact (in. lb.) ..	75	78	49	71	66	53
Delayed Tests.						
Static (lb.)	54	62	44	135	129	82
Impact (in. lb.) ..	58	53	30	51	54	34

The results (average values only) obtained from the subsidiary tests are given in Table 2.

TABLE 2.

Direction of Grain.	Plain Nail (No. 3).	v Processed Nail (No. 5).	Plain Nail (No. 3).	v Cement-coated Nail (No. 4).	Plain Nail (No. 1).	v Plain Nail (No. 3).
	lb.	lb.	lb.	lb.	lb.	lb.
Side ..	177	264	186	197	147	206
End ..	130	170	..	..	..	..

5. Discussion of Results.

Expressing the results obtained with the processed cement-coated nail as shown in Table 1 as percentages of the corresponding plain nail values, yielded the following table:—

TABLE 3.

—	Intermediate.			Delayed.		
	Side.*	End.	Mean.	Side.*	End.	Mean.
Static.						
Plain	100	100	100	100	100	100
Processed cement-coated ..	190	176	183	228	186	207
Impact.						
Plain	100	100	100	100	100	100
Processed cement-coated ..	89	108	98	94	113	103

* Average of tangential and radial tests.

A statistical analysis of the results of the delayed tests verified the following points which were in complete agreement with the analysis of the immediate tests:—

(*a*) A highly significant difference (at the 1 per cent. level of probability) exists between the results obtained with the processed cement-coated nail and the plain nail under static loading.

(*b*) Under impact loading there is no significant difference between the nails.

(*c*) No significant difference was observed between the holding power of nails driven into the radial and tangential faces.

The most important feature of this experiment is the falling off in holding power of the new plain nail. In Table 4 where the nail is compared with similar nails manufactured and tested previously, it can be seen that the use of bunya pine instead of hemlock has had little effect on the mean static holding power although there is less difference between the side and end grain results than was the case with hemlock. It is therefore evident that the change in species has not been responsible for the low holding power recorded for this new plain nail.

TABLE 4.

Direction of Grain.	Tested in Hemlock.		Tested in Bunya Pine.	
	Plain Nail, Tested 1933.	Plain Nail, Tested 1937.	Plain Nail (from 1937), Tested 1943.	Plain Nail, Tested 1943.
Side	220	194	177	125
End	110	108	130	98
Mean	165	151	153	111

Initially, it was noticed that these nails had a very smooth and polished surface and it was not surprising that the reduced friction resulted in a marked drop in holding power. Two probable explanations were put forward to account for this, firstly that the improved methods of wiredrawing have caused a decrease in the efficiency of the nails or that the nails used in these tests were supplied straight from the machine and had insufficient time to "age," it being presumed that the "ageing" process was a slight corrosive action increasing the frictional resistance of the nail to drawing.

After analysis of the delayed tests, however, the second explanation was found to be inapplicable as it would be expected that "ageing" would have taken place when the nails stood for three months resulting in a decrease in the relative efficiency of the processed cement-coated nail. This was not the case, the relative efficiency not altering significantly from the immediate to the delayed tests.

The tests on the cement-coated nail (No. 4) and the processed nail (No. 5) were included to check the effect of the change of species and their relation to the plain nail (No. 3) after being in stock for some years. It was found, in general, that the holding power of these nails bore the same relationship to the plain nail (No. 3) as that determined in previous tests, but when compared with the plain nail (No. 1) their relative holding powers increased considerably. It will be noted from Table 2 that the original processed nail is at least as good as the new processed cement-covered nail, thus the addition of the cement-coating treatment is apparently not justified.

In order to obtain a more adequate estimation of the relative efficiency of the two nails, plain and processed cement-coated, the method suggested by Langlands (loc. cit.) was adopted whereby allowance is made not only for the two types of test, static and impact, but also for the effect of delaying the pulling of the nails. In Tables 5 and 6 the method of deriving the relative efficiency factor for the processed cement-coated nail is shown in detail.

This efficiency factor of 150 obtained for the processed cement-coated nail indicates that it is definitely superior to the plain nail as present manufactured, although, as mentioned above, the cement-coating does not appear to be justified.

TABLE 5.—COMPOSITE FIGURES FOR STATIC AND IMPACT HOLDING POWER.

Weights—(*a*) Immediate tests x 1.
(*b*) Delayed test x 2.

Nail.	*a* Immediate.	*b* Delayed x 2.	*a* + *b*.	Composite Figure = $\frac{a+b}{3}$
Static.				
Plain	100	200	300	100
Processed cement-coated	183	414	597	199
Impact.				
Plain	100	200	300	100
Processed cement-coated	98	206	304	101

TABLE 6.—COMBINED COMPOSITE FIGURES.

Nail.	Static.	Impact.	Average.
Plain	100	100	100
Processed cement-coated ..	199	101	150

It must be remembered that the efficiency value is not comparable with previous tests owing to the marked decrease in holding power of the plain nail.

Since the holding power of a nail varies directly with the length and the diameter,* lighter and/or shorter cement-coated processed nails will have the same holding power as plain nails. However, in case construction, factors other than direct holding power are of importance and must be taken into consideration.

It should also be noted that the maximum size and number of plain nails that can be used in boxes and crates is insufficient to develop properly balanced designs and, therefore, it is recommended that cement-coated processed nails should be used in the same sizes as plain nails, so making a much stronger container with little increase in cost. If it is essential that there should be no increase in cost, cement-coated processed nails one gauge lighter than plain nails could be used.

* Wood Handbook. United States Department of Agriculture (1935).

The Protection of Split-ring Connectors Against Corrosion.

*By B. Whitington, B.Sc., B.E.**

Summary.

Over a period of five years a number of tests have been made on the relative protective values of sixteen different treatments against corrosion, and analyses of the results have shown conclusively that the most effectual and economical anti-corrosive treatment for split-ring connectors is the hot-dip process of zinc coating (galvanizing).

1. Introduction.

Modern connectors for increasing the efficiency in timber joints were the outcome of practice developed in Europe during and subsequent to World War 1. One of these designed for structural timber work was the split-ring connector. Although these have been used in Europe and America for many years with softwoods, in practically all cases dry or semi-dry, no serious weakening of the rings by corrosion of the metal was met with. In 1936 the Council's Division of Forest Products undertook a comprehensive series of strength tests on a variety of timber joints, using green Australian hardwoods and split-ring connectors; and it was found that because of the much greater shrinkage of the timber the behaviour of the rings in green hardwoods was different from that in dry or semi-dry softwood: for example, in hardwoods with the members at right angles to each other the strength of the joint decreased as the timber dried out.

2. Vulnerability of the Rings to Corrosive Attack.

The smaller split-rings of $2\frac{1}{2}$ in. inside diameter are rather thin ($\frac{1}{8}$ in. and 3/16 in.), and it was decided to examine the influence of corrosion on them, and develop some method of treating the rings that could be practically applied and commercially used to prevent loss of metal and avoid consequent weakening of the ring. It was known that many hardwoods, especially when green, had a very corrosive influence on unprotected steel, and so, early in 1938, a systematic series of tests was devised to investigate the problem and evaluate the effectiveness of the application of sixteen different types of protective coatings.

3. Procedure Adopted.

The treated rings were inserted into pre-cut grooves in the green timber specimens, in the same manner as would be adopted in an actual structure, and untreated rings were included in each specimen to act as controls. The specimens were then exposed to severe conditions, and the rings were examined after the lapse of two years and also after an interval of five years. The amount of corrosion was determined by the loss of weight of the ring after removal of the corrosion products, and the relative efficiency of the treatments was thereby indicated.

* An officer of the Division of Forest Products.

4. Materials Used: Split-rings and Timber.

The mild steel split-rings used were made from flat bar $\frac{3}{4}$ in. wide by $\frac{1}{8}$ in. thick (at present 3/16 in. thick rings are used, but these were not available in 1938), and the internal diameter of the rings was $2\frac{1}{2}$ in. The timber chosen for the tests was green karri (*Eucalyptus diversicolor*), because this was known to be a corrosive Australian structural timber.

5. Treatments Used on the Rings.

The various treatments that were given to the rings are listed in Table No. 1. In column 2 of the table the materials used for each treatment are given; the proportions of the ingredients used for each treatment are given in column 3; the method of applying the coat is given in column 4; and the actual weight of the coat determined by weighing the ring before and after applying the coat is given in column 5. Columns 6 and 7 respectively show whether a ring has received a priming coat of red lead by means of the letter P in column 6, and the final conditions of the coat, tacky or dry, by the letters T or D in column 7.

All rings were first thoroughly sandblasted to remove mill scale or rust. With the exception of treatments 15 and 16, which were given by outside firms, all the others were carefully processed and applied in the laboratory; all necessary precautions were taken to ensure an adherent coat without pinholes or other blemishes.

6. The Test Specimens.

Each of the test specimens, of which there were 96, was made up of two 4 in. x 2 in. x 10 in. outer pieces of karri and a 4 in. x 3 in. x 10 in. central piece; grooves for the rings were cut in the faces of these pieces by means of a special groove-cutting tool, so that when the three pieces were assembled with four rings they formed one test specimen as shown in the Fig. 1.

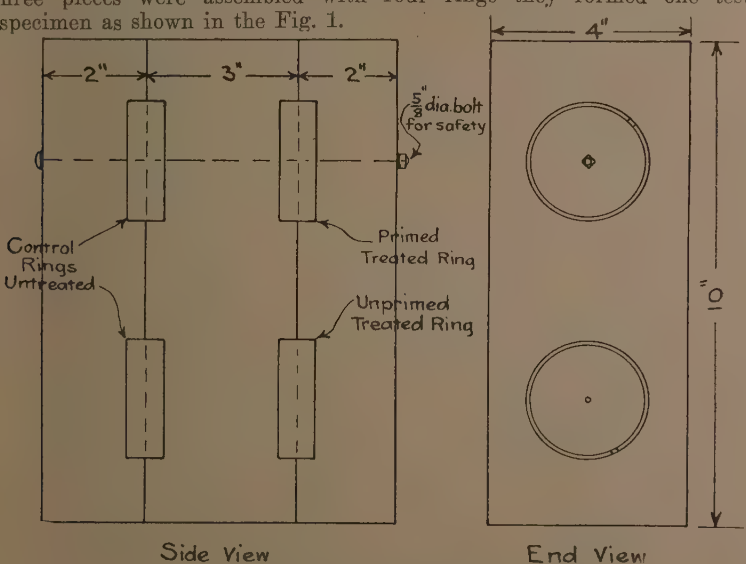

FIG. 1.—Assembly of timber pieces and rings.

TABLE 1.—LIST OF TREATMENTS GIVEN TO THE RINGS TO PROVIDE PROTECTIVE COATS.

Number of Treatment.	Materials Used.	Proportions of Ingredients Used.	Method of Applying the Treatment.	Weight of the Coat applied per Ring.	Primer, if used,* Red Lead, 14 g.; Linseed Oil, 2·7 c.c.	Condition of Coating.†
				g.		
1	Lead Phthalate in Tung Oil	10 g. 10 c.c.	Brushed on cold	0·5	P	D
2	Zinc Dust in Linseed Oil	14 g. 2·8 c.c.	Brushed on cold	0·4	P	D
3	Coal Tar Pitch Al. Powder in Benzol	3 g. 2 g. few c.c. Benzol	Brushed on cold	0·4	P	D
4	Al. Paste in Long Oil Varnish	14 g. 14 c.c.	Brushed on cold	0·4	P	D
5	Al. Powder Lanoline	2 g. 14 g.	Brushed on cold	0·4	P	T
6	No Coroso	Trade Product	Brushed on cold	..	..	T
7	Alloprene in Tung Oil	0·7 g. 9 c.c.	Brushed on cold	0·3	..	D
8	Lanoline, Paraffin with Naphtha	9 g. 1 g.	Brushed on cold	0·4	P	T
9	Petroleum Grease, Zinc Dust	7 g. 13 g.	Brushed on cold	0·3	P	T
10	Coal Tar Pitch, Portland Cement, and Benzolene	26 g. 6·5 g. 6·5 g.	Brushed on cold	0·4	P	D
11	White Lead Tallow	12 g. 40 g.	Applied hot to warm ring	0·3	P	T
12	Horizontal Retort Tar Coke Oven Pitch	10 g. 10 g. heated together	Dipped into hot bath	0·2	..	D
13	Basic Lead Chromate in Linseed Oil	14 g. 6 c.c.	Brushed on cold	0·2	P	D
14	Petroleum Jelly ..	..	Brushed on cold	..	..	T
15	Parkerized	..	..	..	..	D
16	Galvanized ..	..	Dipped into Molten Zinc	2·65	..	D

* P = Primed. † T = Tacky; D = Dry.

TABLE 2 - Results of Examination of Rings after 2 and 5 years' Exposure.

Number of the Treatment	Nature of the Treatment given to the Rings	Control Rings: Loss of Wt. of Ring caused by corrosion, 2 years	Control Rings: Loss of Wt. of Ring caused by corrosion, 5 years	Control Rings: Max. Loss on any one Ring, 2 years	Control Rings: Max. Loss on any one Ring, 5 years	Treated Unprimed Rings: Loss of Wt. of Ring caused by corrosion, 2 years	Treated Unprimed Rings: Loss of Wt. of Ring caused by corrosion, 5 years	Treated Primed Rings: Loss of Wt. of Ring caused by corrosion, 2 years	Treated Primed Rings: Loss of Wt. of Ring caused by corrosion, 5 years	REMARKS: After 2 years' exposure	REMARKS: After 5 years' exposure
		%	%	%	%	%	%	%	%		
1	Lead Phthalate in Tung Oil *	12.7	23.5	16	30	1.2	6.0	nil	1.0	Slight pitting	Rings corroded and pitted
2	Zinc dust in Linseed Oil *	17.5	20.0	18	27	1.9	1.3	nil	nil	" "	Unprimed corroded, primed not corroded
3	Coal Tar Pitch Al-powder in Benzol *	16.2	25.8	25	55	2.1	6.3	0.1	1.7	" "	Unprimed and primed rings both corroded
4	Al-paste in Long Oil Varnish *	13.5	19.4	18	25	1.2	0.7	0.4	nil	" "	Unprimed little corrosion, primed little pitting
5	Al-powder in Lanoline *	13.9	20.7	19.5	25	0.5	4.0	0.8	1.0	" "	Unprimed and primed rings both corroded
6	No Coroso (a trade product)	14.6	20.0	17	22	2.5	7.7	-	-	Considerable pitting	Good deal of corrosion
7	Alloprene in Tung Oil *	15.5	19.5	20	26	5.0	6.7	2.3	0.3	"	Unprimed corroded more than primed
8	Lanoline and 10% Paraffin thinned with Naphtha *	15.2	19.2	19	25	3.7	6.3	1.1	2.3	Pitting	Unprimed corroded much more than primed
9	Petroleum Grease and 65% by wt. of Zinc dust *	12.8	19.3	16	24	2.6	9.0	0.8	nil	"	Unprimed badly corroded, primed only slightly
10	Coal Tar Pitch with 10% Portland Cement and Benzol *	13.25	16.25	14	18	1.8	6.3	nil	nil	"	Unprimed corroded, primed negligible
11	White Pb and Tallow *	14.4	18.8	18	22	1.8	5.7	0.7	2.3	"	Both unprimed and primed corroded
12	Horizontal Retort Tar † and Coke Oven Pitch	10.8	22.0	14	27	2.9	4.5	1.4	4.5	"	Both unprimed and primed corroded
13	Basic Chromate of Pb in Linseed Oil *	13.65	13.8	17	23	2.5	12.7	2.2	4.0	"	Both unprimed and primed badly corroded
14	Petroleum Jelly	14.9	17.0	19	20	4.7	8.2	-	-	Considerable pitting	Good deal of corrosion
15	Parkerised	14.4	21.5	18	35	1.5	4.5	-	-	4 rings pitted on outer face especially	Badly corroded
16	Galvanised 2.65 g. of Zn per Ring	14.25	15.7	16	24	nil	nil	-	-	NO PITTING	NO CORROSION
	Overall average percentage loss	14.2	19.3								

* Primed with Pb_3O_4.

† Primed with its own coating.

Note: The rings used averaged 100 g. each. Three primed rings and three unprimed rings were used for the treatments, except with treatments Nos. 6, 14, 15, and 16, where six unprimed rings were used. In each of the sixteen experiments, six rings were left untreated as Controls.

7. Exposure of the Specimens.

The 96 test specimens were placed in cool store (range of temperature 37° to 40°F.) for three months and kept watered each morning. They were then taken out, and placed in the open and kept covered and wet for six months by watering every morning; twice a week they were sprinkled with common salt. For the rest of the time they were left without covering and were spread apart to allow free circulation of air between them. No attempt was made to tighten up the bolts.

8. Examination of the Test Specimens.

Three separate examinations of the test specimens were made; the first was made on 48 of the specimens twelve months after assembly, the next was made at the end of two years on the same 48 specimens; and the last was made on the other 48 specimens at the end of five years.

The first examination was purely qualitative, and it was seen that the corrosion of the untreated control rings was not as severe as might have been anticipated under such drastic conditions; also, those rings that had received a priming coat prior to the overcoat showed practically no corrosion. It was then decided to re-assemble these 48 specimens and open them again at the end of two years.

The second and third examinations were on a quantitative basis, and the extent of the corrosion was determined by the loss of weight of the ring. The results of these examinations are all shown in Table 2.

Where the rings were badly corroded, as all the controls were, the timber pieces had to be split longitudinally to release the rings which had become cemented into the grooves in the timber. The products of corrosion had then to be chipped off the rings. Since the products of corrosion remain as a closely adherent cover on the rings, they act as a partial protection against further corrosion, and so the percentage loss by corrosion is not proportional to the time. The average loss of weight of the controls shown in Table 2 is 14·2 per cent. after two years as compared with 19·3 per cent after five years.

The results for the unprimed and primed rings given in Table 2 show the advantage gained by applying a priming coat of red lead in linseed oil. It must be remembered, however, that this priming coat would have to be given in the factory immediately the rings had been sandblasted, and although the small cost of the actual materials in the priming coat might make it a worth-while consideration, the time taken to apply it and then dry it, might make the cost prohibitive.

In every way the galvanizing with zinc stands apart from all the others, and in this connexion it must be remembered that this particular coat is not merely a cover; the zinc metal in the process of galvanizing actually penetrates the base metal of the ring, forming several zinc-iron alloys all of which have valuable properties of high resistance against corrosion. It can therefore be recommended as the best treatment. Plate 4 shows the marked contrast of a badly corroded untreated ring alongside galvanized rings after two and five years of exposure, and the composite section shows further the loss of metal of the untreated ring.

Stock and Scion Investigations.

III. The Root-systems of Some Own-rooted Apple Trees.

*By L. A. Thomas, M.Sc.**

Summary.

A study has been made of the root systems of 39 varieties of two- and three-year-old own-rooted apple trees, produced by layering. Wide differences were found in the lateral spread of the roots, their penetration in depth, the number of main roots formed, the size of the trees produced, and the ratio by weight of shoot growth to root growth.

1. Introduction.

In a previous publication (Thomas, 1938) it was mentioned that the practice of encouraging root-grafted trees to become established on their own roots was prevalent in the Stanthorpe district; and that very little was known concerning the nature of such root systems.

A survey of the available literature reveals a certain amount of direct and indirect information. Lincoln (1936) published a series of photographs of root systems of three-year-old own-rooted apple trees, and in describing them states that "the photographs do not give an adequate picture of the depth of penetration since many small roots were undoubtedly cut when the tree was lifted." Yet a study of these photographs shows many points of agreement with the present work upon similar varieties.

Lincoln (1939) also made a study of the root systems of trees which were blown over in a hurricane. The nature of the rootstock could not be determined, but there was no doubt that some of the trees were scion-rooted. The variety McIntosh was used as a standard of comparison, and the following groupings of trees on their ability to grip the soil are based on observations where they stood close to McIntosh. Some varieties, such as Gravenstein, made trees which were less stable than McIntosh; other varieties, such as Ben Davis, Delicious, Golden Delicious, and Northern Spy, were more root firm than McIntosh.

Yocum (1937) studied the root systems of the variety Delicious when grown in two soil types, clay loam and loess, under a variety of cultural conditions. Under clean cultivation a generalized root system was produced; the roots penetrated deeply and spread widely.

A study of the nature of the root systems of certain apple varieties when grown entirely on their own roots was thought necessary to gain, in a short time, an estimate of their suitability to local conditions; and to give an indication of the type of root system that a root-grafted tree would produce when scion-rooted. A common argument advanced against the use of Northern Spy as a rootstock is that it produces a shallow root system; any own-rooted apple tree that produces a similar root system might, therefore, be regarded as unsuitable.

* An officer of the Division of Plant Industry, stationed at Stanthorpe, Queensland.

2. Material and Method.

The own-rooted trees were obtained by layering (Thomas, 1938) and were planted as one-year-old shoots after trimming back all roots to 3 inches. The first planting was made in July 1936 and consisted of 3 trees of each variety planted at 3 feet apart in rows 5 feet distant. The varieties used and their placement from south to north were as follows:—In the western row: Emperor Alexander, Zuccamaglio, Kirks, Ben Davis, Niedwetzkyana, Lady Carrington, Allsopp's, Bramley's Seedling, Red Gravenstein, and Golden Delicious; in the middle row: Marjorie Hay, Mona Hay, Stayman's Winesap, Lady Carrington, Widdup, Laxton's Superb, Boswell, Stewart's Seedling, Granny Smith, Jonathan; and in the eastern row: Delicious, McIntosh, Peasgood, King Cole, Foster, Milton, Madino. Stool beds were situated 5 feet distant from the eastern and western rows.

The second series of trees was planted in July 1937 and consisted of 3 trees of each variety at 4 feet apart in rows 5 feet distant, 3 trees of each variety constituting a row. From east to west, the rows were Granny Smith, Jonathan, Delicious, Red Gravenstein, Crofton, Stayman, Stewart's Seedling, and Ivory's Double Vigour Stock.

The third series of trees was planted in 1939 and consisted of 4 trees of each variety planted 4½ feet apart in a row, with rows 3 feet distant. The order of planting from north to south was: East Malling clonal Northern Spy, Red Statesman, King David, Lord Nelson, Democrat, Willie Sharp, Nickajack, Duke of Clarence, Dunn's Favourite, William's Favourite, Commerce, and Senator.

All trees were planted to a depth of 9 to 10 inches and were headed back at a height of 15 inches from the ground level. A uniform winter pruning was given throughout. The trees were unfertilized and kept clean cultivated to a maximum depth of five inches.

The first and second series of trees were excavated in the dormant season in June and July 1939, the third series at a similar period in 1942. The "skeleton" method of Rogers and Vyvyan (1934) was used. The lateral spread and the depth of penetration of the roots were recorded, their character and abundance noted, and the amount of fibre observed. The root systems of certain varieties were mapped, and for this purpose the middle tree of each group was chosen. The fresh weight of the shoots and roots was obtained to determine the shoot/root ratios. For this purpose, all roots were removed from the underground trunk and this portion was included in the weight of the shoots.

3. The Soil.

The soil on which the trees were grown is of granitic origin and in profile shows a grey sandy layer (0–7 in.), above a buff or yellow-brown sand (7–13 in.), which is followed in depth by a deeper coloured brown sand (13–19 in.), then a yellow-red sandy clay (19–30 in.), and a red and white cemented clay layer. Ironstone rubble generally occurs in the deeper coloured brown sand. The figures given are for the profile for the Jonathan tree shown in Fig. 3 and are only an example, as depth of soil varies in this district over small areas.

4. Results.

The results of the observations made from excavating the root systems are summarized below, and the weights of the trees and the shoot/root ratios given in Tables 1, 2, and 3.

The First and Second Series of Trees.

Allsop's Early. Small root system with few main roots. Roots thin, ¼ inch in diameter or less, numerous, descending to 12 inches at the extremities with practically all roots below 6 inches. Roots average 3 feet in length and carry abundant fine fibrous roots. One tree showed uneven rooting.

Ben Davis. Roots thin, ¼ to ⅜ inch in diameter, medium in number, averaging 12 main roots per tree; non-branching; arise from near ground level to the base of the underground stem; roots up to 3 feet long with abundant fibre. At 2 feet from the trunk, many roots descend to 14 to 19 inches; only a few roots as shallow as 5 inches.

Boswell. Roots ⅜ inch in diameter, numerous, evenly developed; radius of spread 36 inches; well supplied with much branched, fleshy rootlets, cf. Stewart's Seedling. Roots 9 inches deep at 1 foot from the trunk and extend horizontally at this depth; odd sinker roots to 20 inches.

Bramley's Seedling. Roots strong and thick, ¾ inch in diameter, medium number, up to 6½ feet long, fibre abundant, occurring in tufted bunches along the length of the roots; roots mainly at 7 to 9 inches and descending to 12 inches at ends; evenly developed system.

Crofton. Roots mostly ⅜ inch in diameter, supplied with medium amount of fibre; radius of spread 30 inches. Root system much branched and evenly developed with nearly all deep roots. At 2 feet from the trunk, they reach a depth of 22 inches, with only an occasional shallow root, 6 to 10 inches.

Delicious. Roots mostly ⅜ to ½ inch in diameter, numerous; fibre is scanty, but bunches of long, thin rootlets occur towards the ends of the larger, shallower roots; radius of root spread 36 inches; root system is branched and evenly developed; some roots deep throughout their length, while others have sinker roots down to 18 inches. See Fig. 1. Two-year-old trees showed the same radius of spread and the same type of root system with the deepest roots at 17 inches.

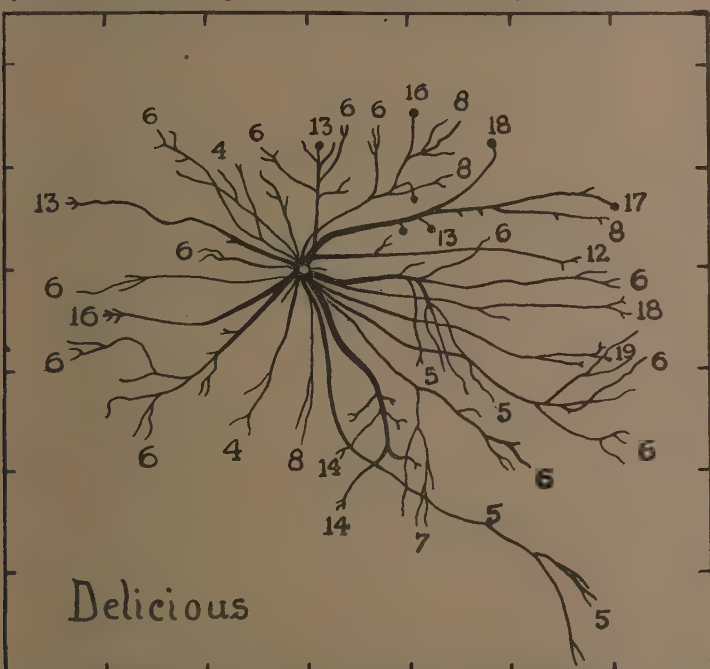

FIG. 1.—Delicious. Depth of rooting shown in inches, scale one inch to one foot. Where full black circles are shown, this indicates that the roots descend almost vertically at these points to the figured depths.

Emperor Alexander. Roots ½ inch in diameter, carrying abundant fibre which occurs in bunches throughout the length of the main roots; roots up to 3 feet long, fairly well branched; roots mostly 5 to 8 inches deep with odd ones descending to 12 inches. Evenly developed root system.

Foster. Shallow root system. Roots ⅜ inch in diameter, fibre scanty; up to 4½ feet long, sparsely branched. Roots all in the grey sandy layer, mostly 6 inches in depth with no deeply pentrating roots.

Golden Delicious. Roots variable in size; a few ⅜ inch in diameter, but many as thin as ⅛ inch; medium amount of fibre; the 3 trees showed a one-sided root development; roots run horizontally at the 6- to 9-inch level with little tendency to penetrate in depth.

Granny Smith. Extremely poor root development. The underground trunk is crowded with short, fleshy and wiry roots only a few inches long. The root system is unevenly developed with one or two main roots 18 to 24 inches long.

Gravenstein. Unevenly developed root system, with one or more large coarse roots 1 inch in diameter; roots up to 6 feet long, with a medium amount of fibre; ends of some roots much divided. Many shallow roots. The two-year-old trees had roots up to 5 feet long and occurred at 3 to 8 inches in depth, with an odd root descending 12 to 15 inches. These again were uneven root systems. See Fig. 2.

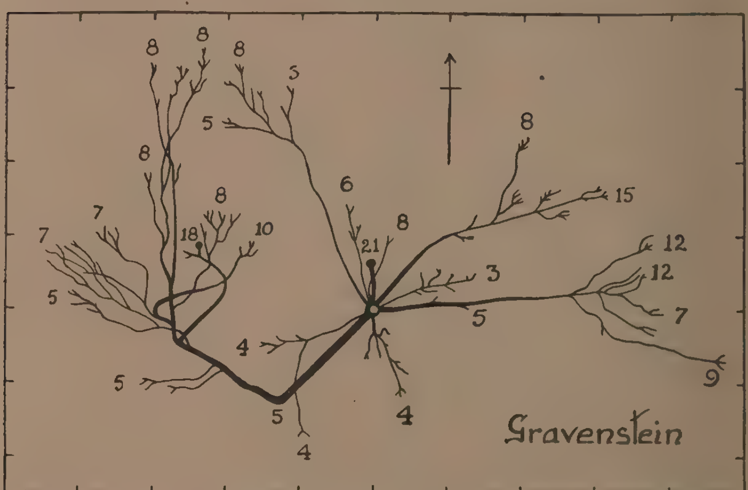

FIG. 2.—Gravenstein. Depth of rooting shown in inches, scale one inch to one foot. Where full black circles are shown, this indicates that the roots descend almost vertically at these points to the figured depths.

Jonathan. Roots about ½ inch in diameter; numerous, supplied with medium amount of fibre. Roots penetrate deeply into the yellow-red clay to a maximum depth of 28 inches; very few roots in the sandy top layer; sparsely branched, evenly developed root system. The two-year-old trees had all roots below 9 inches; they grew in the yellow-brown sand at 12 to 15 inches; the deepest roots were at 22 inches. See Fig. 3.

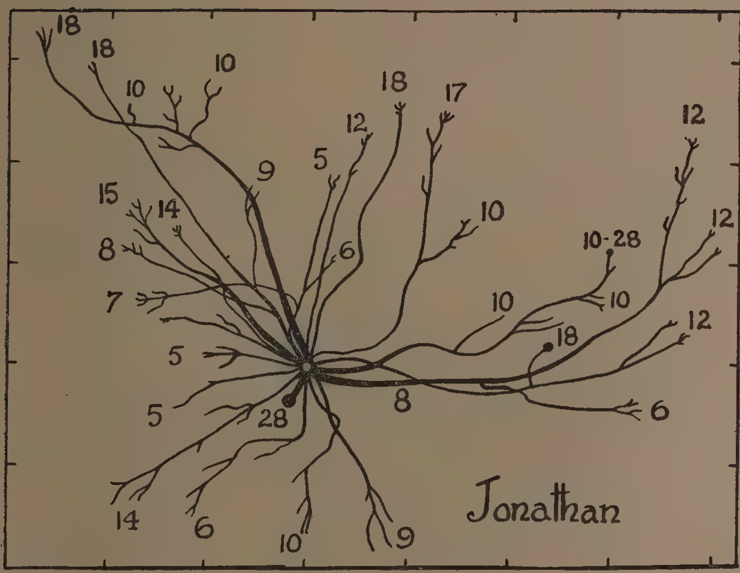

FIG. 3.—Jonathan. Depth of rooting shown in inches, scale one inch to one foot. Where full black circles are shown, this indicates that the roots descend almost vertically at these points to the figured depths.

King Cole. Stout roots varying from ½ to 1 inch in diameter, carrying fair to poor amount of fibre; roots up to 4½ feet long; some shallow roots at 4 inches, but mostly at 7 inches, descending at ends in some cases to 14 inches; evenly developed, branching root system.

Kirks. Roots ¼ to ⅜ inch in diameter, medium in number, carrying abundant fibre; shallow root system, with little root branching; roots confined mostly in the grey, sandy layer at depths of 4 to 7 inches; only occasional roots near the trunk descend to 14 inches; roots up to 3 feet long; masses of short, fleshy roots on the trunk from the ground level down.

Lady Carrington. Roots ⅜ to ½ inch in diameter, supplied with plentiful fibre; roots up to 6 feet long, but mostly three feet; practically no branching; medium number of roots (10). Shallow system with roots at 3 to 6 inches, with little tendency to deepen with extension; odd sinker roots to 12 inches; tendency to one-sided development.

Laxton's Superb. Main roots thin, ¼ inch or less in diameter, carrying medium amount of fibre, radius of spread 30 inches; majority of roots at 4 to 6 inches, with practically no roots below 8 inches. Evenly developed root system.

Marjorie Hay. Roots ¼ to ⅜ inch in diameter, carrying medium amount of fibre; radius of spread 30 inches; roots are well branched, occur at 5 to 9 inches in depth with sinker roots along their length penetrating as deep as 24 inches. See Fig. 4.

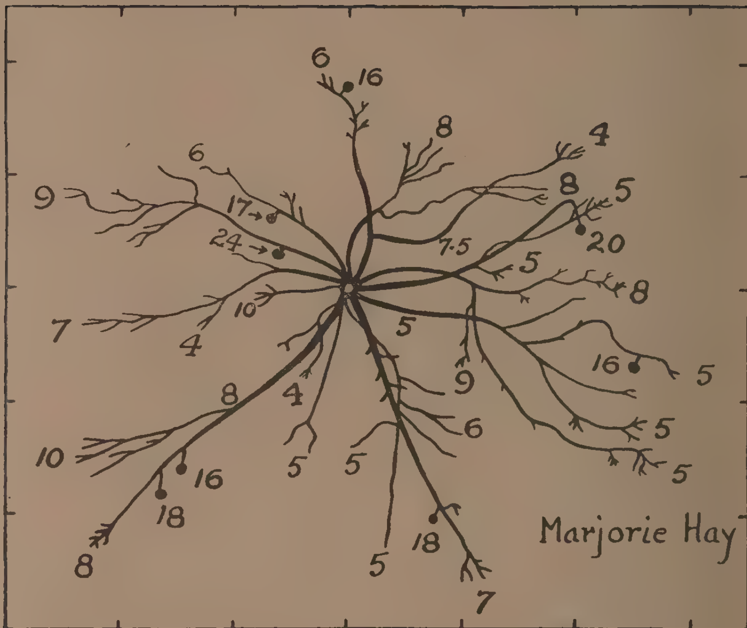

FIG. 4.—Marjorie Hay. Depth of rooting shown in inches, scale one inch to one foot. Where full black circles are shown, this indicates that the roots descend almost vertically at these points to the figured depths.

Madino. Main roots ½ inch in diameter, carrying abundant short, fleshy roots throughout their length; roots mainly at 8 or 9 inches with occasional one to 12 inches. Underground trunk covered from the ground level downwards with abundant short, fleshy roots. Evenly developed system with few main roots, 6 to 10 in number, averaging 30 inches long.

McIntosh Red. Main roots ½ to 1 inch in diameter, with plentiful fibre; roots 3 feet long and unbranched; average of nine main roots per tree; unevenly developed root system. Roots are shallow, 5 to 7 inches in depth, with no deeply descending roots.

Milton. Main roots ½ to 1 inch in diameter, carrying abundant fibre. Roots are shallow, 4 to 6 inches in depth, with most roots shallower at their extremities; some roots are sinuous in depth, i.e., they go deeper for a distance and then ascend; roots 4 to 4½ feet long showing a tendency to an uneven distribution.

Mona Hay. Roots thin, ¼ to ½ inch in diameter, with a poor amount of fibre. They originate over the whole depth of the underground trunk, but mainly at the 5 to 9-inch levels. The roots spread horizontally at this depth; some roots arising from beneath the trunk descend to 12 or 14 inches; an even spreading root system with numerous main roots; as many as 25 roots at 2 feet radius from the trunk; roots 3½ to 4 feet in length.

Niedwetzkyana. Roots mainly ½ inch in diameter, carrying abundant long fibre; rooting system shallow, 3 to 7 inches in depth, occasional small sinker roots to 12 or 14 inches; non-branching root system with an average of 10 roots per tree; even spreading system with roots 3 feet in length.

Peasgood. Roots ½ to ¾ inch in diameter, with a good amount of fibre; roots mainly shallow at 5 inches, with sinker roots given off which gradually descend to a maximum depth of 19 inches, but mostly to 14 inches; an evenly-developed root system with much branching; up to 22 roots in a circle of 1 foot radius from the trunk; roots up to 4½ feet long.

Stayman's Winesap. Roots ½ inch in diameter, fibre good; roots shallow at 5 to 7 inches, with an occasional root descending 12 to 14 inches; an even spreading, non-branching system with rather few main roots, an average of 9 per tree; radius of root spread 30 inches. The two-year-old trees had shallow roots 4 to 7 inches in depth, all confined to the grey sandy layer; roots were up to 3½ feet long, averaging 12 per tree. Two out of the 3 trees showed a one-sided root development.

Stewart's Seedling. Main roots thin, ¼ to ⅜ inch in diameter, carrying a plentiful amount of long, thin, fleshy rootlets; roots descend rapidly from their origin on the underground stem to a depth of 9 to 12 inches and extend at such levels. The roots are short, 2½ to 3 feet in length, but have numerous branchings and an even spread. Two-year-old trees had roots ⅜ to ½ inch in diameter with a medium amount of fibre; practically all roots of one tree descended to 22 inches close beneath the trunk, but the other two did not show this feature so markedly. Rooting systems were branched, even-spreading with roots up to 3 feet long.

Widdup. Roots ½ to ¾ inch in diameter, stout, with a poor amount of fibre, deeply pentrating, descending to 26 inches within 18 inches from the trunk; some roots almost vertical in growth; rooting system branching, with a medium number of roots; radius of spread 30 inches.

Zuccamaglio. Roots ½ inch in diameter, with a medium amount of fibre; 6 to 8 inches in depth, descending near extremities to 13 to 15 inches, with a maximum depth for some of 19 inches; only a few shallower roots. Roots show only a small number of branchings, are medium in number, there being 14 in a circle of 2 feet radius; radius of spread 3½ feet, with an odd root 5 feet in length.

The Third Series of Trees.

Commerce. In layer beds yielded 94 per cent. rooted shoots. Shoots had many coarse roots with abundant fibre; rooting very good. Three-year-old trees had strong root systems with many coarse roots ½ to 1 inch in diameter, with numerous ¼-inch roots; roots grew from all levels of the underground trunk. Fangy roots were observed on all trees; these descended to 20 to 24 inches to reach the hard pan at 1 foot away from the trunk. Some roots arising from the base of the underground trunk at 9 to 10 inches depth, ascend to higher levels at 4 to 5 inches with extension in length, but most long roots showed deeper rooting at 12 to 20 inches. Roots up to 5½ feet long. Root system branching and even-rooted.

Democrat. In layer beds yielded 60 per cent. rooted shoots. These had a few fleshy roots and showed poor rooting. Three-year-old trees averaged 10 main roots per tree ½ to ¼ inch in diameter, carrying a good amount of fibre. Roots arise as a basal whorl from the underground trunk and generally become shallower with extent and grow at 3 to 6 inches in depth. Only a few roots penetrate to 12 or 18 inches at their ends. Even-rooted, shallow, little branched root system.

Duke of Clarence. In layer beds yielded 86 per cent. rooted shoots. Shoots had thin, hard roots with fair amount of fibre. Rooting good. Three-year-old trees averaged 11 main roots ¼ and ½ inch in diameter. Roots mainly occupied the 6 to 8-inch zone, with some small roots as shallow as 2 inches; an occasional root descended to 10 or 18 inches in depth. Fibre good; rooting was basal; roots mainly 3 to 4½ feet long, shallow. An even-rooting, little-branched root system.

Dunn's. In layer beds gave 100 per cent. rooted shoots. Shoots had an abundant mass of thin, fleshy roots. Rooting excellent. Three-year-old trees were of small stature; roots mainly ¼ inch in diameter, averaging only four per tree; two trees each had one ½-inch root; numerous fibrous roots grow the whole length of the underground stem. Roots are shallow, mainly at 6 to 8 inches deep, with shallower roots at 2 inches and an odd larger root descending to 10 or 12 inches at extremities. Roots average 2 feet in length. Even-rooting, sparse, shallow root system.

King David. In layer beds gave 59 per cent. rooted shoots. Shoots had a few thin, hard roots. Rooting fair. Three-year-old trees averaged 1 ¾-inch root, 7 ½-inch and 3 ¼-inch roots. Roots are shallow, occurring mainly between 4 and 9 inches in depth, with some at 2 inches; fibre poor to medium, but at the ends of main roots occur bunches of thin, wiry roots about 1/16 inch in diameter. Roots all took their rise from the base of the underground trunk. Unevenly developed, shallow root system.

Lord Nelson. In layer beds gave 96 per cent. rooted shoots. Shoots had coarse, hard roots, with fair amount of fibre. Rooting ability fair to poor. Three-year-old trees averaged 13 main roots, mainly ½ and ¼ inch in diameter, with medium fibre. Roots are shallow, mainly 4 to 6 inches deep, with an occasional root to 12 inches. Evenly developed, shallow root system.

Nickajack. In layer beds gave 96 per cent. rooted shoots. Shoots had thin, hard roots, and many fleshy roots. Rooting good. Three year-old trees had strong rooting systems, averaging 2 ¾-inch roots, 5 ½-inch and 6 ¼-inch roots per tree; abundant fibre; roots snap easily and could be described as "carroty." No deep roots; they mainly occur in grey, sandy top soil at 2 to 8 inches in depth. Roots arise basally from the trunk and are 2½ to 3½ feet long. Shallow, slightly unevenly developed root system.

Red Statesman. In layer beds gave 83 per cent. rooted shoots. Shoots have few thin, hard roots. Rooting fair. Three year old trees have strong roots ¾ to ½ inch in diameter and practically no fibrous roots. Roots descend quickly to depths of 15 to 18 inches, with some roots to 22 inches. Roots arise at all levels from the underground trunk and even those arising 2 inches below ground level rapidly descend. No root less than 6 inches deep. Root system coarse, even-rooting, and deep.

Senator. In layer beds gave 95 per cent. rooted shoots. Shoots had abundant thin, hard roots, cf. Commerce. Rooting good. Three-year-old trees averaged 10 main roots per tree, mainly ½ and ¼ inch in diameter, with some ¾ inch roots; fibre plentiful. No roots occurred within 5 inches of the surface; most roots deepen with extent, the ends penetrating 12 to 22 inches. A tendency was shown to a one-sided root development with the roots showing better development to the south where there were no contiguous trees. Roots 3 to 5 feet in length.

William's Favourite. In layer beds gave 36 per cent. rooted shoots. Shoots had few thin, hard roots with fair amount of fibre. Rooting fair to poor. Three year-old trees had an average of 6 main roots ½ and ¼ inch in diameter; fibre in medium amount; fibre developed all along the underground trunk; roots arise in a basal whorl and reach depths of 8 to 10 inches at a small distance away from the trunk; ends of roots descend 12 to 18 inches. Small, evenly rooted trees with roots 2 to 2½ feet long.

Willie Sharp. In layer beds yielded 71 per cent. rooted shoots. Shoots had only a few hard, thin roots. Rooting fair. Three-year-old trees had a small number of main roots, averaging 3 ½-inch and 3 ¼-inch roots per tree, with abundant fibrous roots on the underground trunk, cf. Dunn's. Roots non-branching, shallow at 3 to 6 inches deep; an occasional root penetrated to 12 inches. Roots average 3 feet in length. Small, even-rooting, non-branching system.

Northern Spy. This clonal material was obtained from East Malling, England. In layer beds yielded 100 per cent. rooted shoots. Shoots had numerous thin, fibrous and fleshy roots. Rooting good. Three of the four three-year-old trees showed a one-sided root development with the roots occurring to the north where there were no contiguous trees. Roots were stout, 1 to ½ inch in diameter, with some ¼-inch roots, but were variable in number from tree to tree. Roots shallow, mainly 5 to 8 inches deep, with extremities of some roots descending 12 to 19 inches; roots up to 6 feet long.

TABLE 1.—OWN-ROOTED APPLE TREES: FIRST SERIES.

Variety.	Weight of Tree.	$\frac{\text{Stem}}{\text{Root}}$ Ratio.	Variety.	Weight of Tree.	$\frac{\text{Stem}}{\text{Root}}$ Ratio.
	lb. oz.			lb. oz.	
Allsopp's ..	3 6¼	4·4	McIntosh Red	4 8¼	1·8
	2 13	4·1		3 5½	1·9
	2 8	4·0		4 10¾	1·8
Delicious ..	7 14¾	3·2	Foster ..	5 3¾	1·7
	9 4½	3·7		6 4½	1·8
	7 6	3·1		4 7¾	1·8
Golden Delicious	5 11½	3·3	Laxton's Superb	2 2½	1·6
	3 9¼	3·2		2 12	1·7
	4 7	2·7	Bramley's ..	4 8¾	1·4
Marjorie Hay ..	2 7¼	2·6	Seedling	6 0¾	1·8
	3 10¾	2·9		5 4	1·5
	3 14	2·9	Stewart's ..	2 12¾	1·4
Madino ..	2 12¾	2·5	Seedling	2 6	1·6
	2 9	2·6		1 13¾	1·5
	4 7¾	2·5	Niedwetzkyana	7 10	1·5
Widdup ..	5 6¼	2·5		4 2¾	1·6
	4 6	2·5		6 3½	1·4
			Ben Davis ..	2 1¾	1·3
Lady Carrington	4 7¾	2·5		3 10¼	1·6
	3 1	2·4		3 9¾	1·7
	2 15	2·4	King Cole ..	7 4¼	1·4
	4 12¼	2·4		4 8¾	1·5
	3 10	2·2		5 1	1·5
	3 12	2·5	Stayman's ..	2 4	1·5
Jonathan ..	8 12½	2·5	Winesap	2 9	1·4
	6 15¾	2·3		3 0¾	1·7
	5 7¾	2·4	Peasgood ..	4 4¼	1·3
Zuccamaglio ..	5 10½	2·2		6 13¼	1·4
	6 9	2·3		5 7¼	1·3
	7 5¾	2·1	Emperor ..	5 9¾	1·2
Boswell ..	2 12½	2·2	Alexander	4 10	1·6
	2 13¼	2·4		5 13¼	1·2
	3 2½	2·4	Red Gravenstein	5 15¼	1·1
				3 6½	1·1
Kirk's ..	3 13	2·5		6 0¼	1·2
	3 4	2·3	Milton ..	3 11	1·1
	3 14½	2·4		3 11¾	1·0
Mona Hay ..	4 12½	2·2		4 4¼	1·0
	5 4	2·0	Northern Spy ..	5 5½	2·8
	4 5¼	1·9		10 0	2·7

TABLE 2.—OWN-ROOTED APPLE TREES: SECOND SERIES.

Variety.	Weight of Tree.	Stem/Root Ratio.	Variety.	Weight of Tree.	Stem/Root Ratio.
	lb. oz.			lb. oz.	
Jonathan ..	3 3¾	2·2	Stewart's	4 14	1·4
	3 6	2·1	Seedling	3 6	1·5
	3 12	2·1		4 3½	1·6
Delicious ..	5 0½	2·1	Stayman's	5 9¼	1·4
	3 10	2·0	Winesap	2 10	1·4
	4 12½	2·0		4 6½	1·3
Crofton ..	8 1¾	2·0	Red Gravenstein	4 9¼	1·1
	6 12	1·9		3 2¾	1·1
	4 7	2·0		3 10¼	1·2

TABLE 3.—OWN-ROOTED APPLE TREES: THIRD SERIES.

Variety.	Weight of Tree.	Stem/Root Ratio.	Variety.	Weight of Tree.	Stem/Root Ratio.
	lb. oz.			lb. oz.	
Commerce ..	6 11¾	2·0			
	11 10¾	1·5	Senator ..	9 4	3·2
	12 13¼	1·3		5 0¾	4·0
	13 14	1·6		10 3¼	4·0
Democrat ..	5 15¼	1·8		9 15	3·2
	4 9	1·7			
	4 4¼	2·2	William's	2 6½	1·9
	6 15	2·1	Favourite ..	3 7½	1·8
Duke of Clarence	4 10¾	1·6		4 2¼	1·7
	5 2½	1·6			
	4 10¾	1·6	King David ..	7 6	2·0
	5 4¾	1·4		7 9¼	1·9
Dunn's ..	2 13	2·0		5 6¼	1·9
	5 8	2·3			
	3 8	2·2	Lord Nelson ...	6 11¾	1·2
	4 5¾	2·0		6 7½	1·4
Nickajack ..	8 9¼	1·8		3 4½	1·2
	6 0	1·8	Willie Sharp ..	4 8¾	2·0
	6 14	2·2		3 6¼	1·9
	8 12½	2·2		2 3	2·2
Red Statesman	6 4	3·0			
	5 1¾	2·5	Northern Spy ..	10 2½	2·4
	6 15¼	3·1		7 4¼	2·3
	6 0¼	2·6		13 0¾	2·8

A study of the tabulated information discloses many distinctions between the types of root systems formed by own-rooted trees. Deep-rooting types, such as Commerce, Senator, Red Statesman, Jonathan, and Crofton may be contrasted with shallow-rooting types, such as Stayman's Winesap, McIntosh Red, Milton, and Democrat. Wide differences are shown in the number of the main or "anchor" roots per tree; on the one hand we have Dunn's with 4, William's Favourite and Willie Sharp with 6 as an average, and on the other Ben Davis with 12 and Peasgood with 22 within a circle of 1 foot radius from the trunk.

Some root systems, such as Stayman's Winesap, have no tendency to branch with extension, while others like Mona Hay and Delicious have definite branching types of root systems.

Unevenly developed and one-sided root systems are illustrated by Gravenstein (Fig. 2); other such types are Northern Spy, Golden Delicious and McIntosh Red. Further, some varieties develop only a basal whorl of roots, e.g., Democrat, Duke of Clarence, and King David, while other varieties, such as Red Statesman and Commerce, have strong roots originating at all levels from the underground trunk; others again develop masses of short, fibrous roots up to the ground level, e.g., Dunn's and Willie Sharp.

Differences in vigour between the varieties can be observed in the tables, where tree weights are given to represent such a factor. The weights of the heaviest or most vigorous trees to the nearest lb. are Commerce, 14; Northern Spy, 13; Senator, 10; and Delicious, 9. These are to be compared with those varieties producing the lightest weight trees of similar age, viz., Allsopp's, 3½ lb.; Stayman's, 3 lb.

The ratio of stem weight to root weight gives a series of figures ranging from 1·0 for Milton and 1·1 for Red Gravenstein up to 4·0 for Senator and 4·4 for Allsopp's. There appears to be no correlation between this shoot/root ratio and vigour as expressed by tree weight. Comparing Allsopp's with Senator, both of which have similar shoot/root ratios, we find the largest Senator tree weighs 10 lb. 3¼ oz., as against the largest Allsopp's with a weight of 3 lb. 6¼ oz.

The variety Granny Smith has given an unsatisfactory performance as an own-rooted tree. It appears that it is susceptible to injury during periods of high air temperatures. The three three-year-old trees were dwarfed in stature and each season when air temperatures reached about 90° F. or more, the leaves on these trees curled, browned, and died, after which no new growth was made for that season. New, healthy growth was made in each succeeding spring, but the same phenomenon was repeated each summer. The three trees planted in July 1937 grew well until the following mid-January, when the leaves died; the bark of the trees was sun-scalded and the trees failed to leaf out in the spring. Shoots of Granny Smith in the layer beds have been reported to be susceptible to heat injury (Thomas, 1938).

5. Discussion.

As the trees studied were planted rather closely, it was thought that the configuration of the root systems would be altered owing to root competition. Rogers and Vyvyan (1934) have shown that root systems of certain apple stocks are modified in radial spread when roots from a strongly growing stock invade territory near the roots of another similar or weaker growing stock. Substantial agreement with this type of root competition was found in this study. On the other hand, Hearman (1936) suggests from a study of Northern Spy root systems that the nearness of other roots causes the Spy roots to descend. A careful examination of the above root systems does not support this contention. Moreover, many of the apple varieties have been shown to possess completely shallow rooting systems. Furthermore, the trees dug

at two years after planting, which were more widely spaced, showed essentially the same characteristics as the three-year-old trees, upon which the main conclusions are based.

Although the number of trees of any one variety studied was limited, yet the figures obtained for the shoot/root ratios are close enough to suggest that they have real meaning.

Local plantings of root-grafted apple trees have been made of some of the varieties mentioned above. It must be admitted that this type of tree is not strictly comparable with an own-rooted tree, as a foreign root is grafted to the scion, but as these trees are planted deeply to encourage scion rooting, in a matter of time they become scion-rooted to a greater or lesser degree, depending upon the amount of development of the "nurse" root.

In the case of the variety Gravenstein, it is agreed that the root-grafted trees are shallow rooted. An opportunity was taken to examine some fifty trees which were discarded after some years as being unsatisfactory. These proved to be scion-rooted and were dwarfed trees with thin, spindly leaders.

The variety Granny Smith in two orchards ceased growth at about eight to ten years of age. In one case, a row of Granny Smith on seedling stocks alongside are at least twice the size of the root-grafted trees and are still making good growth.

In the other orchard, an examination of the root systems showed no trace of the original "nurse" root, which was inserted in the side of the scion originally. The roots of these trees ran horizontally at seven to ten inches in the soil.

A further orchard planting of Granny Smith root-grafts has been replaced owing to their unsatisfactory growth. Other plantings of this scion variety in deeper soil appear to be satisfactory at their present age of ten to twelve years.

Little can be said of the other varieties, as most plantations are young, but in the search for trees with a better performance than those on Northern Spy rootstocks, the evidence to date indicates that the performance of different varieties on their own roots may be expected to vary considerably.

6. References.

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A Preliminary Field Test of Insecticides against Potato Moth, *Gnorimoschema operculella* (Zell.)

*By G. A. H. Helson, M.Sc.**

Summary.

1. In a field experiment near Canberra in 1943-44, phenothiazine gave excellent control of potato moth, *Gnorimoschema operculella* (Zell.), in a growing Brownell potato crop.

2. It protected the growing tops from attack by larvae of the moth and also appeared to protect the developing tubers.

3. Its protection of the foliage in the plots where it was used increased the yield of these to more than double the yield produced on untreated plots.

4. Synthetic cryolite and lead arsenate plus 5 per cent. sodium aluminium sulphate were the next most effective materials.

5. It remains to be shown whether these materials will give satisfactory control when used at commercial rates of application and frequency of treatment.

1. Introduction.

In recent years the acreage planted to potatoes in Australia has been expanded to meet a growing wartime demand, and the time has come when any large, additional production will be achieved only by increasing the yield per acre. Each year severe crop losses in all the mainland States of the Commonwealth are caused by attack of the potato moth, *Gnorimoschema operculella* (Zell.), not only on stored tubers but also on the growing crop, where both the tops and the tubers may be severely damaged. In dry seasons these losses are particularly severe and may amount to many thousands of tons. Added to this is a shortage of labour which often makes it difficult or impossible to lift a crop when attack by the insect threatens to become very severe.

In the past the insect has proved most difficult to control, and no satisfactory method of achieving this was known. The protection of stored tubers has received some attention (Helson, 1942; Lloyd, 1944), and recently derris has shown promise when used as a spray on the growing tops (Lloyd, 1943), but large quantities of derris are not easily obtainable. A dust consisting of lead arsenate and lime (Newman and Morgan, 1937) is only partially effective when used on the growing crop. Thus it is apparent that some form of field control, if it can be found, is of great importance.

This article deals with the results of a field experiment carried out on the Council's experimental farm near Canberra during 1943-44. The experiment was part of a larger test designed to find a satisfactory insecticide for the control of the pest, therefore heavy dosages of the various materials were used in order to ensure that plants were thoroughly covered with each insecticide. These dosages were heavier than would be applied in commercial practice, and the question of practical application was left to be developed after promising insecticides had been found.

* An officer of Division of Economic Entomology.

The measure of control effected by one of the substances tested, phenothiazine, was so striking that it was decided to make the results generally known by publishing them below. Also, this material gave such complete protection to the foliage that it was possible to demonstrate by direct experiment the effect on yield of moth infestation of the foliage. Demonstration of this effect is most important and supports previous evidence that such losses in yield are appreciable and that the yield of infested plants is directly related to the amount of leaf area left undamaged (Bald and Helson, 1944). The work on insecticides is still in progress and a full account will be published later.

2. Field Design and Method.

The field plan of the experiment was a randomized block design for eight treatments consisting of seven sprays and control and replicated four times. There were 56 Brownell plants to a plot, consisting of eight rows of seven plants spaced 2 feet apart in the row to facilitate rating for moth damage. The field was planted on December 16, 1943, and fertilized with sulphate of ammonia and superphosphate. Furrow irrigation was first made on January 19, 1944, and there were four waterings at approximately fourteen-day intervals. Throughout the course of the experiment, practically no rain fell and severe moth infestation occurred on all untreated plants.

The first application of five of the spray treatments was made on January 18, 1944, and four subsequent applications occurred at fourteen-day intervals. The first application of the other two spray treatments was delayed until full flowering ("late timed") and repeated twice at fourteen-day intervals. The treatments were as follows:—Phenothiazine, 3 lb.; synthetic cryolite, 6 lb.; lead arsenate plus 5 per cent. sodium aluminium sulphate, 3 lb.; lead arsenate plus 5 per cent. sodium aluminium sulphate "late timed," 3 lb.; basic copper arsenate, 10 lb.; basic copper arsenate "late timed," 10 lb.; basic copper arsenate, 5 lb. (pounds per 100 gallons of water).

The phenothiazine used was pure recrystallized material to which a wetting agent had been added. The synthetic cryolite was specially prepared so that the ratio of aluminium fluoride to sodium fluoride was adjusted to correspond with natural cryolite. An average of 27 gallons of spray material was used for each treatment on all replicates.

The method of rating plants for moth damage described elsewhere (Bald and Helson, 1944) was used to study the effect of the treatments on the foliage throughout the growing period of the plants. This method consists of rating plants by comparison with a series of standards which have known proportions of their foliage destroyed. and to use the ratings as a measure of infestation. The ratings were 0 to 5, 0 representing a plant on which damage was negligible and 5 a plant on which all or nearly all the leaf tissue was destroyed. The ratings 1 to 4 represented successively greater destruction of leaf tissue. The first rating of the crop was made immediately before the first spraying and was followed by four other ratings at varying intervals during the growth of the crop.

3. Results.

The five ratings for moth damage to the tops are shown in Table 1. The figures are the mean rating per plant for all replicates of each treatment and corrected for missing plants.

TABLE 1.—MEAN PLANT RATINGS FOR DAMAGE TO BROWNELL POTATO TOPS BY LARVAE OF THE POTATO MOTH IN CANBERRA.

Treatment.	Plant Ratings Made on (Date).				
	17.1.44.*	10.2.44.	21.2.44.†	29.2.44.	14.3.44.
Phenothiazine	0·03	1·01	0·60	0·10	0·00
Synthetic cryolite ..	0·00	1·08	1·90	2·40	2·40
Lead arsenate + sodium aluminium sulphate ..	0·02	1·01	2·02	2·60	2·50
Lead arsenate + sodium aluminium sulphate ("late timed")	0·04	1·20	2·30	2·70	2·70
Basic copper arsenate (10 lb.)	0·05	1·10	2·30	2·80	2·90
Basic copper arsenate (10 lb. "late timed") ..	0·01	1·50	2·40	3·05	3·04
Basic copper arsenate (5 lb.)	0·02	1·02	2·10	2·80	3·07
Control	0·05	1·5	3·05	3·40	3·50
Date of spray application	18.1.44	2.2.44	15.2.44	1.3.44	14.3.44

* Plant rating made one day before first spray application.
† Plant rating made six days after the first "late timed" application.

There was a uniformly low infestation immediately prior to the application of the first spray, and after this the table shows that the amount of damage to the tops rapidly increased. The greatest increase occurred on the control plots and the least on the plots treated with phenothiazine. On these latter plots there was an initial increase in damage during the fortnight which elapsed between the first and second ratings, resembling the increase which occurred on all the other plots. After the second rating, however, subsequent treatment with phenothiazine reduced and finally eliminated further damage to the tops.

The relative efficiency of the other materials for the control of moth damage to the tops is shown by their position in the table. Without statistical analysis it is obvious that the difference between phenothiazine and control and all other treatments is highly significant. Statistical analysis of the other treatments (excluding phenothiazine because it was obviously lower than the rest of the treatments, and because the variance between its replicates was obviously lower than the variances between replicates of other treatments) showed that the differences between synthetic cryolite, lead arsenate, and basic copper arsenate

(10 lb.) and control were all highly significant, and between basic copper arsenate (10 lb. "late timed") and basic copper arsenate (5 lb.) and control were significant at the 1 per cent. and 5 per cent. levels respectively.

The efficiency of phenothiazine was remarkable, because it gave almost complete protection throughout the growing period of the plants, and enabled them to grow vigorously into large bushes which did not have any of the bottom leaves or the lateral shoots totally destroyed by larvae of the moth (Fig. 1). The plants in plots treated with cryolite were only slightly less vigorous than those in the phenothiazine plots, but attack of the lower leaves and lateral shoots occurred. Plants treated with all other materials suffered the loss of most of the large lower leaves and severe attack on the bottom laterals. Thus smaller plants were produced.

Fig. 1.—Photograph of a typical plant in Brownell potato plots treated with phenothiazine, taken on March 8th, 1944, six days before the last plant rating.

Plants treated with basic copper arsenate, however, appeared to recover later in the season by producing new top growth and laterals faster than these were attacked by larvae of the moth (Fig. 2). This material, however, did not afford sufficient protection during the critical period earlier in the season. Plants in the control plots were severely attacked (Fig. 3) and at the end of the season were almost completely defoliated.

FIG. 2.—Photograph of a typical plant in Brownell potato plots treated with basic copper arsenate (10 lb.) taken on March 8th, 1944, six days before the last plant rating.

FIG. 3.—Photograph of a typical plant in untreated Brownell potato plots, taken on March 8th, 1944, six days before the last plant rating.

The yields from the plots at harvest are shown in Table 2. The table shows the details of total yield of tubers, and weight of sound and damaged tubers, for all replicates of each treatment corrected for the number of plants missing at harvest. The relative effectiveness, as shown by yields from the different treatment plots, is indicated by the position of the yields in the table. The effectiveness of the various insecticides, as measured by the increase in yield when compared with the yield from the control plots, was of the same relative order as was found from the plant ratings. Thus, plots treated with phenothiazine produced the greatest yield, followed next by cryolite and lead arsenate. The total yield and yield of sound tubers produced on plots treated with phenothiazine was outstanding; these plots showed an increased yield of sound tubers of 2·13 times the yield from control plots. Similarly cryolite increased yield by 83 per cent., and lead arsenate by 72 per cent. Statistical analysis showed that the difference in yield between phenothiazine and control, both on total weight and on weight of sound tubers, was significant at the 1 per cent. level, and the differences between the other two treatments and control were significant at the 5 per cent. level. The weight of potatoes damaged by larval attack was least on the plots treated with phenothiazine, and there was little difference between the other plots and control, except for basic copper arsenate (5 lb.) where the greatest weight of tubers was damaged. The reason for this is unknown.

TABLE 2.—TOTAL YIELDS FROM PLOTS IN POTATO MOTH INSECTICIDE EXPERIMENT NEAR CANBERRA 1944.

The table shows the increase in yield effected by the various treatments, the total yield of tubers, and weight of sound and damaged tubers (corrected for the number of plants missing at harvest).

Treatment.	Total Weight of Tubers.	Weight of Sound Tubers.	Relative Yield of Sound Tubers. Control = 100.	Weight of Tubers Damaged.
	lb.	lb.		lb.
Phenothiazine	348	306	213	42
Synthetic cryolite	328	264	183	64
Lead arsenate + sodium aluminium sulphate	310	248	172	62
Lead arsenate + sodium aluminium sulphate ("late timed")	295	245	170	50
Basic copper arsenate (10 lb.) ..	257	197	137	60
Basic copper arsenate (10 lb. "late timed")	213	159	114	54
Basic copper arsenate (5 lb.) ..	268	179	124	89
Control	211	144	100	66
Minimum differences between treatments totals significant at—				
5 per cent.	97	107	74	32
1 per cent.	132	146	101	44
0·1 per cent.	179	197	137	60

4. Discussion.

The foregoing results show that in this experiment phenothiazine protected the foliage of the growing crop to a remarkable degree, thus considerably increasing yield. Synthetic cryolite and lead arsenate protected the tops to a lesser extent. It was found also that after the rating for moth damage on February 21, 1944, when severe infestation was evident, large numbers of moths, many of which had obviously migrated from surrounding plots, were sheltering during the day among plants treated with phenothiazine and cryolite because these offered greater protection from the hot dry weather. This, of course, increased the risk of infestation on plots treated with these materials, therefore their effectiveness was probably greater than indicated by the plant ratings as shown in the last column in Table 1.

The yield figures are quite obvious and need little further discussion. However, the data also suggest that phenothiazine directly afforded some degree of protection to developing tubers, and that neither cryolite nor lead arsenate provided any such direct protection (last column Table 2). It should be stressed that the yield figures were obtained from plots grown in a dry district where severe attack occurs every year, and that in districts where attack is not so severe the increase in yield produced by phenothiazine, cryolite, and lead arsenate may not be so marked as in this experiment. However, the severity of damage caused by potato moth in growing crops in a large proportion of seasons in the Crookwell and Orange districts of New South Wales, in some areas in Western Australia and, at times, in other potato growing districts, is comparable with the damage in the Canberra area. It still remains to be shown whether a practical method of application can be developed whereby crops would be treated at 100-120 gallons to the acre using power-spraying machinery to treat a number of rows simultaneously, and whether phenothiazine, cryolite, or lead arsenate will still control potato moth infestation satisfactorily when applied at the lower dosage with such machinery.

The time and frequency of application of the spray treatments are also very important aspects of the problem. It is fairly certain that the critical period begins at early flowering (unpublished data) and that the first application should, therefore, probably be applied at this time. The number and timing of subsequent applications has still to be determined.

5. Acknowledgments.

Thanks are due to Mr. G. A. McIntyre for assistance with the field plan and statistical analyses, and to Mr. T. Greaves for assistance in the field.

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Dormancy and Hardseededness in *T. subterraneum.*

2. The Progress of After-harvest Ripening.

*By K. Loftus Hills, B.Agr.Sc.**

Summary.

Eleven lots of seed of subterranean clover raised in 1940, and eighteen in 1941, were stored indoors at Moss Vale, New South Wales. Samples were removed at intervals and germinated at 22°C.

Seed lots which showed greatly delayed germination required over twelve months' storage to reach their maximum speed of germination, those with moderately delayed germination required from seven to twelve months, and the remainder rquired from three to seven months.

1. Introduction.

The causes of the failure of some samples of new season's seed of subterranean clover to germinate within the time specified under standard seed testing conditions have been discussed by the writer in the first paper of this series (Loftus Hills, 1942). Seed which is physiologically immature or dormant will mature and become fully viable after an interval, the length of which depends on the species and variety, the conditions of storage of the seed, and the environmental history of the plant prior to harvest. Little information is available concerning the course or the duration of this after-harvest ripening† process in subterranean clover, although it is generally believed that reasonable germination of dormant seed can be obtained during the autumn following harvest. Woodforde (1935) considers that normal germination may be expected after a period of storage of from three to four months. The period required for full maturation in some dormant cereal samples is as short as three weeks (Larson, *et al.*, 1936), whilst in species such as *Ambrosia* several years may elapse before the seed becomes fully viable (Davis, 1930).

The experiments described in this paper were designed to determine the length of the after-harvest ripening period in seed of subterranean clover of varying degrees of dormancy stored indoors at Moss Vale, New South Wales.

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* An officer of the Division of Plant Industry.

† Seed of certain species, although morphologically mature when harvested, will not germinate immediately and requires a further period of ripening before it reaches physiological maturity. This after-harvest maturation is sometimes referred to as "after ripening," but in the writer's opinion, this is a misnomer, as the word ripe should imply complete morphological and physiological maturity. The term after-harvest ripening has therefore been used in this paper. Mature seed is defined as seed which has reached both morphological and physiological maturity.

2. Material and Method.

The material for the investigation consisted of 29 lots of seed comprising nine different varieties of subterranean clover grown at Moss Vale and Canberra during 1940, and at Melbourne, Moss Vale, and Canberra during 1941. The plants were harvested in December and the burr sent to Moss Vale immediately, where the seed was threshed out on a rubber hand-thresher.

The 1940 seed consisted of eleven lots, two of which were grown at Canberra and nine at Moss Vale. They were stored in packets in a laboratory drawer whence samples, each consisting of 200 seeds, were removed for testing in January, April, July, and November 1941, and in February 1942.* There was not enough seed of most lots to complete the series, so the samples available were spread, somewhat at random, over the five tests.

There were eighteen lots of seed in 1941, five of which were grown at Melbourne, eight at Canberra, and five at Moss Vale. Twelve samples, each of 200 seeds, were counted out from each lot. The 216 samples were percussed as in the previous year, and they were then stored in packets in a laboratory drawer. Three samples were removed from each lot of twelve, for testing in March, May, and July 1942, and in February 1943. Although the varieties flowered at different times they ripened within a few days of each other, so that the period between harvest and testing was practically equal for all lots of seed.

3. Germination Technique and Presentation of Results.

The germination technique used was similar to that previously described by the writer.†

The number of swollen seeds which had germinated at each stage of the tests was expressed as a percentage. These percentages were then plotted graphically against the number of days from the commencement of the test. An example of the type of curve obtained is shown in Fig. 1. Such curves give a dynamic picture of the course of germination, but are too cumbersome for publication. The percentage co-ordinate has therefore been arbitrarily fixed at 60 per cent., and the

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* Before testing, each sample of seed was percussed in a mechanical shaker for five minutes to make the seed coat permeable to water. It is generally found that over 90 per cent. of the seed will absorb water and swell after this treatment.

† All germination tests were carried out on moist blotting paper in Petri dishes placed in a germination oven set at 22°C. Additional water was added as required, which was usually at intervals of two or three days. Previous experience in germinating *T. subterraneum* had shown the necessity of ample moisture in the substrate. Work by Aitken has shown the efficiency of percussion in overcoming the impermeability of the seed coat, and tests by the writer have shown that it is at least as effective as the more usual scarification with sandpaper. It has the advantage of being more easily controlled and of involving somewhat less work. The usual procedure with the dormancy tests was to do an initial separation and count of swollen, hard, and germinated seeds at from 48 to 72 hours after the commencement of the test, and thenceforth at intervals of from one to six days to record the number of additional hard seeds which had swollen, and swollen seeds which had germinated.

values of the variable, i.e., the intervals in days from the commencement of the test to the time when 60 per cent. of swollen seed have germinated, have been set out in tabular form. In most cases interpolation was necessary.

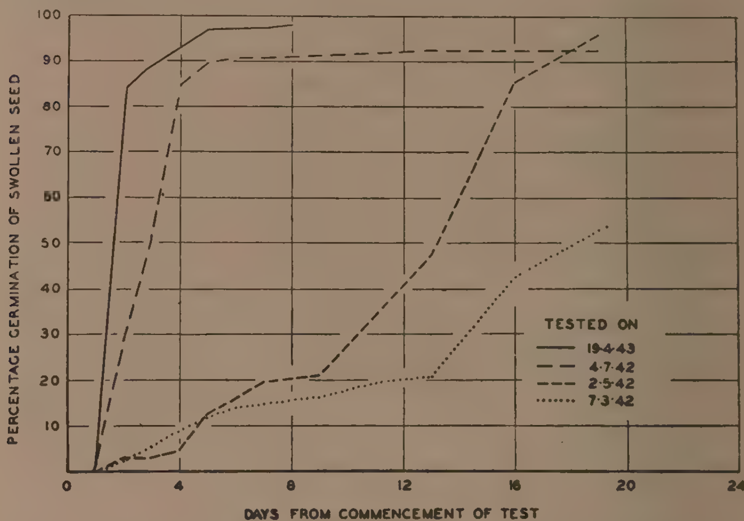

FIG. 1.—The germination of swollen seed of the variety Mulwala grown at Moss Vale in 1941, when tested at intervals throughout the after-harvest ripening period.

4. Results and Discussion.

The intervals in days between the commencement of the germination tests and the stage when 60 per cent. of the swollen seed had sprouted, for each lot of seed at each stage of after-harvest ripening, are set out in Tables 1 and 2.

Most of the seed in the 1941 series (Table 1) was very dormant. The January test, which was concluded on the tenth day, showed that only one lot of seed of the eleven in the series had reached the arbitrary figure of 60 per cent. by the end of the tenth day. In seven samples less than 1 per cent. of the swollen seed had sprouted during the same period. The April, July, and November figures show in general a progressive decrease in the time required to reach the 60 per cent. figure. There are three exceptions to the general trend. Two are of a minor nature and are believed to be due to experimental error. The high figure obtained in the July test for the Tallarook seed grown at Moss Vale may have been due to a sampling error, but the possibility of the development of secondary dormancy should not be lost sight of. However, as the writer has not encountered a similar effect in the many samples tested at various times, it is considered more probable that the explanation lies in the first suggestion. After-harvest ripening continued in most cases after November, for in seven of the eleven seed lots there was a further decrease between November and February in the time required to reach the 60 per cent. figure.

TABLE 1.—THE PROGRESS OF AFTER-HARVEST RIPENING IN SEED OF SUBTERRANEAN CLOVER GROWN DURING 1940.

Variety.	Place Grown.	Number of Days between Commencement of Germination Test* and Sprouting of 60 Per Cent. of the Swollen Seed; when Tested: January, 1941.†	April, 1941.	July, 1941.	November, 1941.	February, 1942.
Mt. Barker	Moss Vale	‡	27·8	12·2	13·0	4·8
Mt. Barker	Moss Vale	‡	27·3	18·8	11·8	< 4·0
Mt. Barker	Moss Vale	‡	20·1	12·7	9·5	4·5
Mt. Barker	Canberra	‡	..	11·6	..	< 4·0
Tallarook ..	Moss Vale	§	5·5	12·3	5·7	< 4·0
Tallarook ..	Canberra	5·2	..	< 4·0	..	< 4·0
Wenigup ..	Moss Vale	§	17·7	6·9	< 4·0	< 4·0
Wenigup ..	Moss Vale	§	25·7	6·5	< 4·0	< 4·0
Bacchus Marsh	Moss Vale	‡	11·3	< 4·0	5·0	< 4·0
Macarthur ..	Moss Vale	‡	18·6	11·2	7·8	< 4·0
Nangeela ..	Moss Vale	‡	14·8	9·5	7·2	< 4·0

* At 22°C.
† Concluded at tenth day.
‡ < 1 per cent. sprouted by tenth day.
§ < 7 per cent. sprouted by tenth day.

The results of the 1942 series are set out in Table 2. The material is, on the average, much less dormant than that of the previous year but, except in two or three instances, where the seed showed very little delay in germination in March 1942, there was a progressive decrease up to July in the number of days required to reach 60 per cent. germination of swollen seed. Only in the case of Mulwala and Mt. Barker seed raised at Canberra and the Burnerang seed at Moss Vale was there a further appreciable decrease when tested in April 1943. Although the figures quoted in Table 2 do not indicate that the two lots of seed of the variety Wenigup increased in speed of germination after March, they did in fact do so, for example 78 per cent. of the swollen seed of one lot germinated by the second day of the March test, but at the same stage of the May test 98 per cent. had sprouted.

The degree of dormancy or of delayed germination of the 29 lots of seed examined varied considerably. Seed of the variety Wenigup grown during 1941 showed very little delay in germination when tested in March 1942, whereas Mt. Barker seed grown at Moss Vale during 1940, when tested in April 1941, required 27 days before 60 per cent. of the swollen seed had germinated. Samples showing a small degree of dormancy completed their after-harvest ripening quickly and reached their maximum speed of germination by the following autumn. Those exhibiting intermediate degrees generally continued to increase in speed of germination to from seven to twelve months after harvest, whilst those of long delayed germination were apparently not fully matured until more than a year after harvest. The question of the differences in delayed germination between the several varieties has not been discussed, for it is hoped to do so in a subsequent paper of the series, when additional data will be presented.

TABLE 2.—THE PROGRESS OF AFTER-HARVEST RIPENING IN SEED OF SUBTERRANEAN CLOVER GROWN DURING 1941.

Variety.	Place Grown.	Number of Days between Commencement of Germination Test* and Sprouting of 60 Per Cent. of the Swollen Seed ; when Tested:			
		March, 1942.	May, 1942.	July, 1942.	April, 1943.
Mt. Barker ..	Melbourne ..	18·7	17·0	3·9	4·4
Mt. Barker ..	Canberra ..	11·7	11·9	3·9	2·9
Tallarook	Melbourne ..	5·5	8·4	2·0	2·9
Tallarook	Canberra ..	2·1	2·0	2·0	2·0
Tallarook ..	Moss Vale ..	..	2·0	2·0	..
Bacchus Marsh ..	Melbourne ..	9·6	6·5	2·4	2·4
Bacchus Marsh ..	Canberra ..	5·4	4·3	..	2·4
Dwalganup ..	Canberra ..	2·8	2·0	2·0	2·0
Dwalganup ..	Moss Vale ..	..	4·0	2·1	2·4
Mulwala	Melbourne ..	..	10·2	2·6	2·4
Mulwala	Canberra ..	7·6	8·4	2·4	2·0
Mulwala	Moss Vale ..	21·0	12·1	3·3	2·0
Macarthur ..	Melbourne ..	8·8	4·4	2·6	2·6
Macarthur ..	Canberra ..	3·7	2·0	2·0	2·0
Wenigup	Canberra ..	2·0	2·0	2·0	2·0
Wenigup	Moss Vale ..	2·0	2·0	2·0	2·0
Burnerang ..	Canberra ..	22·5	16·7	7·0	8·7
Burnerang ..	Moss Vale ..	> 25	> 25	> 25	17·2

* At 22°C.

5. Conclusions.

(i) New seasons seed of subterranean clover which showed greatly delayed germination when tested at 22°C., required over twelve months to mature fully when stored indoors at Moss Vale, New South Wales. The delay in germination decreased gradually throughout the period.

(ii) Samples with moderately delayed germination required periods of from seven to twelve months to mature completely.

(iii) None of the 29 lots of seed had matured completely by the third month, but several had apparently done so by the fifth month after harvest.

6. Acknowledgment.

The assistance of Miss Yvonne Aitken of the School of Agriculture, University of Melbourne, in growing seed of several varieties at Melbourne, Victoria, is gratefully acknowledged.

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Dormancy and Hardseededness in *T. subterraneum*.

3. The Effect upon Dormancy of Germination at Three Different Constant Temperatures.

*By K. Loftus Hills, B.Agr.Sc.**

Summary.

Twenty lots of seed of subterranean clover, varying in age from two months to over two years, were germinated at constant temperatures of 10°C., 20°C., and 30°C. Nine lots were retested after a further eleven months.

Samples which showed delayed germination germinated most rapidly at 10°C., less rapidly at 20°C., and least rapidly at 30°C. In general the speed of germination at all three temperatures increased with decreasing dormancy, but at 20°C. the increase was relatively greater, so that the speeds at 10° and 20°C. approached equality. In the case of the older samples germination was fastest at 20°C., less at 10°C., and least at 30°C.

Although the speed at 30°C. increased in most cases with decreasing dormancy, in only one sample did it reach that attained at 10°C. and 20°C. In the case of the seed two or more years old, the time taken for 60 per cent. of the swollen seed to sprout was about four days at 10°C., two days at 20°C., and eight days at 30°C.

1. Introduction.

The temperature adopted by the conference of Australian seed-testing officers for the germination of subteranean clover seed is 20°C. However, dormant samples will germinate only after very long periods at that temperature. It has been shown by Woodforde (1935) that most of such samples will germinate rapidly if the test is commenced at 8°C., and the custom has arisen in certain Australian seed-testing laboratories of germinating dormant subterranean clover seed at low temperatures.

There is an extensive literature concerning the behaviour of mature seed of other species at different temperatures of germination, but precise information about the reaction of seed which is not fully matured after harvest is less common. Kearns and Toole (1939) made a thorough investigation of the interaction of after-harvest ripening and the temperature of germination with several species of *Festuca*. They found that as the seed aged it germinated over a wider range of temperatures, the optimum temperature of germination varying between the several species examined. The optimum constant temperature for fresh or dormant seed of *F. rubra* var. *commutata* was 10°C., but as the seed aged the optimum was raised to 15°C.–20°C. However, other species did not show a relative decrease at the lower temperature as they matured, although fresh seed of all species of fescue required a relatively low temperature for germination.

* An officer of the Division of Plant Industry.

Toole and Hollowell (1939) germinated seed of five annual species of *Trifolium*, including *T. subterraneum*, at constant temperatures ranging from 5°C. to 35°C., and repeated the tests at intervals up to three years after harvest. Germination was best at the lower temperatures, but there was generally little difference below a certain critical temperature, which varied with the species between 20°C. and 25°C.

Germination of seed of *T. subterraneum* was good at temperatures up to and including 20°C., but at 25°C. and higher there was a very sharp decrease. The germination did not increase at three successive tests at monthly intervals after harvest, at any temperature.

On the other hand dormant seed of certain plants, such at water-melon and musk-melon, responds to a higher, rather than to a lower, temperature (Anon., 1936).

The experiments described below were designed to discover the behaviour of mature seed of subterranean clover, and of seed showing various degrees of delayed germination, when germinated at three different constant temperatures.

2. Material and Method.

The tests with fully matured seed were carried out on commercial seed of the varieties Mt. Barker, Bacchus Marsh, Tallarook, and Dwalganup, purchased through trade channels in the late summer of 1941, and on seed of the variety Wenigup grown at Canberra during 1939. Thus at the time of these experiments the seed of the four former varieties was at least two years old, and possibly much older, and the Wenigup seed was four years old. The procedure was similar to that described below, three lots of 200 seeds being used for each test. The mean values for the germination of the five varieties at each of the three temperatures 10°C., 20°C., and 30°C. were plotted graphically. The material used for the tests on young seed was raised in Canberra during 1941 and 1942. The varieties grown in 1941 were Mt. Barker, Bacchus Marsh, Tallarook, Dwalganup, Wenigup, and Burnerang, and in 1942 the same six, with the addition of Mulwala, Macarthur, and Wangaratta. Eighteen lots of 200 seeds were counted out from each variety, and shaken as previously described (Loftus Hills, 1944). Three lots from each variety were germinated at 10°C., three at 20°C., and three at 30°C., in May 1942 and in April 1943, for the 1941 grown seed, and in February 1943 for the 1942 seed. A later series of tests on the latter seed could not be carried out because of wartime circumstances.

The germination technique used and the method of presentation of results are described in the second paper of this series (Loftus Hills, 1944). The temperatures of the germinators fluctuated to some extent. The mean reading of the 20°C. oven was 21·5°C., whilst the 30°C. oven was accurate to within half a degree. The refrigerator unit used for the 10°C. tests was the most variable, daily reading varying between 8°C. and 11°C.

3. Results and Discussion.

(i) *Old Seed.*

The mean values for the progress of germination of five lots of old seed at 10°C., 20°C., and 30°C. are shown graphically in Fig. 1. Germination of all five was faster at 20°C. than at 10°C., and at 10°C. than 30°C. The average time taken for 60 per cent. of the swollen seed to sprout was about four days at 10°C., two at 20°C. and eight at 30°C.

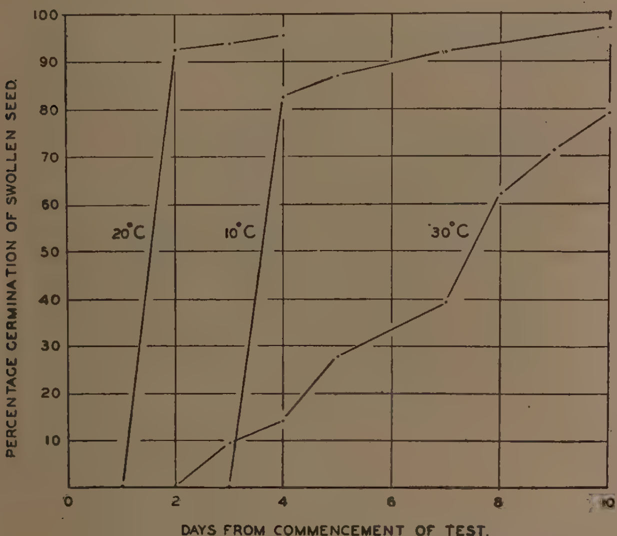

Fig. 1.—The average germination of swollen seed of five varieties when tested at three constant temperatures, two or more years after harvest.

(ii) *Young Seed.*

The number of days between the commencement of the germination tests and the sprouting of 60 per cent. of the swollen seed, for the material grown in 1942 and 1943, at 10°C., 20°C., and 30°C., are set out in Table 1. An example of the curves from which these figures were derived is shown in Fig. 2, which represents the germination behaviour of the variety Bacchus Marsh, grown in 1942, and tested in February 1943.

In columns (2), (3), and (4) of Table 1 (*a*) are set out the results of the 1941 seed tested five months after harvest. In four of the six varieties there is an increase from 10°C to 20°C., and a greater increase from 20°C. to 30°C., in the time required for 60 per cent. of the swollen seed to sprout. In a fifth there is an increase from 20°C. to 30°C., but none from 10°C. to 20°C. The behaviour of the variety Tallarook is anomalous, for there is a decrease from 10°C. to 20°C. followed by an increase from 20°C. to 30°C. When tested eleven months later (Table 1 (*a*), cols. 5, 6, 7), the speed of germination had

increased considerably. In five varieties the time intervals at 10°C. and 20°C. have become practically equal, although detailed reference to the graphs indicates that, taking the progress of germination as a whole, minor differences in favour of the 10°C. series still persist. The time required for 60 per cent. of the swollen seed to sprout at 30°C. has decreased in the varieties Mt. Barker, Dwalganup, and Wenigup, but not in the other three, during the eleven months. The Wenigup seed germinated as rapidly at 30°C. as at 10°C. or 20°C.

The 1942 results are shown in Table 1 (*b*). They illustrate quite clearly the decrease in speed of germination with increasing temperature for the three temperatures investigated.

TABLE 1.—GERMINATION OF FRESH SUBTERRANEAN CLOVER SEED AT THREE CONSTANT TEMPERATURES.

(*a*) *Grown at Canberra in* 1941.

Variety.	Number of Days between Commencement of Germination Test and Sprouting of 60 Per Cent. of the Swollen Seed when Tested:					
	May, 1942.			April, 1943.		
	At 10°C.	At 20°C.	At 30°C.	At 10°C.	At 20°C.	At 30°C.
Mt. Barker	3·5	4·3	19·8	< 3·0	< 3·0	14·8
Bacchus Marsh	3·0	3·7	16·1	< 3·0	< 3·0	16·5
Tallarook	4·3	2·8	12·7	< 3·0	< 3·0	14·8
Dwalganup	3·5	4·2	>35	< 3·0	< 3·0	26·4
Wenigup	< 3·0	< 3·0	17·7	< 3·0	< 3·0	< 3·0
Burnerang	3·9	13·6	27·3	< 3·0	10·0	27·1

(*b*) *Grown at Canberra in* 1942.

Variety.	Number of Days between Commencement of Germination Test and Sprouting of 60 Per Cent. of the Swollen Seed when Tested in February, 1943.		
	At 10°C.	At 20°C.	At 30°C.
Mt. Barker	4·0	16·3	21·1
Bacchus Marsh	4·0	9·7	19·0
Tallarook	4·0	8·3	16·1
Dwalganup	5·9	12·0	27·3
Wenigup	2·9	11·8	20·5
Burnerang	7·6	>36	>36
Mulwala	6·4	19·7	>30
Macarthur	4·4	10·0	21·3
Wangaratta	6·2	29·0	>30

It is clear that seed which shows a considerable delay in germination germinates faster at 10°C. than at 20°C., and faster at 20°C. than at 30°C. For example, 60 per cent. of the swollen seed of Mulwala had sprouted after 6 days at 10°C., after 20 days at 20°C., and after more than 30 days at 30°C. The data presented in Table 1 (*a*) indicate that

as after-harvest ripening proceeds the times required for germination at 10°C. and 20°C. become closer, until finally they are equal. The tests on old seed indicate that ultimately germination at 20°C. is slightly faster than that at 10°C., possibly through a slowing down at 10°C. The present data are insufficient to show whether an optimum germination temperature of 20°C. is characteristic of fully matured seed of maximum energy of germination, or is an indication of the onset of senility.

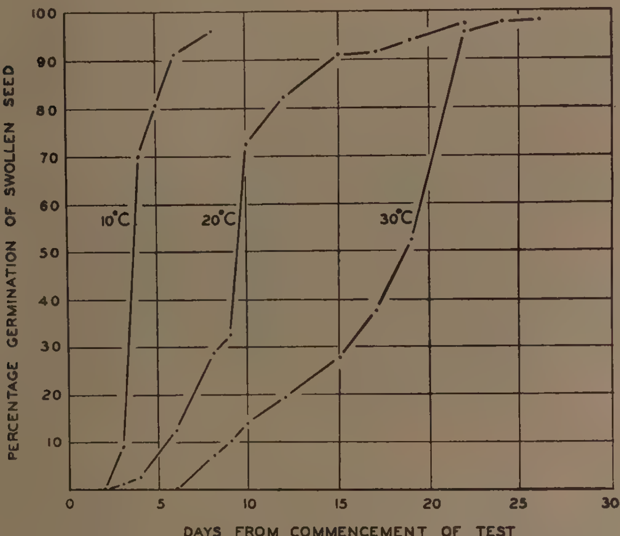

Fig. 2.—The germination of seed of the variety Bacchus Marsh, grown at Canberra in 1942, at three constant temperatures, two months after harvest.

At 30°C. there is a considerable delay in germination, although as the seed matures this delay may be reduced. However, only in one case did the speed of germination at that temperature reach that at 20°C. The data from the tests with old seed indicate that the higher temperature slows down germination. It is possible that occasional seed samples of exceptional vigour are capable of overcoming quickly the inhibition imposed by the higher temperature.

The subterranean clover seed examined by Toole and Hollowell (1939) was evidently well ripened by the time of the first monthly test, because at 20°C. most of the seed had germinated by the sixth day. However, at the higher temperature of 30°C. the germination, even by the 28th day, was as low as 3 per cent. The difference between the speed of germination at 20°C. and 30°C. is greater than any observed by the writer. The explanation may be either in differences of germination technique or differences in the conditions of plant growth.

Although the three successive monthly tests at 30°C. (carried out by Toole and Hollowell) did not show any increase in germination, it is possible that, had the tests been carried on for a further period of a week or more, substantial germination would have occurred, and differences at the successive monthly tests might have then become evident. For example, one sample of dormant seed of subterranean clover tested by the writer at 20°C. showed no germination by the 37th day of the test, yet by the 42nd day 80 per cent. of the swollen seed had germinated. As Toole and Hollowell placed an empirical limit of 28 days upon the length of the germination tests, it is believed that their conclusions, at least in regard to subterranean clover, should be qualified accordingly.

4. Conclusions.

(i) The speed of germination of dormant seed of subterranean clover is dependent upon the temperature of germination, being greater at 10°C. than at 20°C., and much greater at 20°C. than at 30°C.

(ii) As the seed matures the speeds of germination at 10°C. and 20°C. approach equality. The speed of germination at 30°C. may also increase as the seed matures, but only in one case has it been observed to reach that attained at 10°C. and 20°C.

(iii) The speed of germination of old seed was greatest at 20°C., less at 10°C., and least at 30°C.

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The Use of the Hydrometer for the Mechanical Analysis of Soils.

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Summary.

A study of the theory of hydrometers when used for the mechanical analysis of soils has been made and the various possible sources of error have been considered. These errors are :—

1. Those associated with the conversion of density to percentage of soil in suspension.

2. Those associated with the determination of the depth in the suspension at which the density is the same as that measured by the hydrometer.

3. Those due to practical difficulties.

Results from a test hydrometer designed so as to minimize these errors have been compared with results obtained by the standard pipette technique for a number of soils. The mean of all differences, expressed as a percentage of the hydrometer reading and irrespective of sign, is about 5 per cent. This may be considered a creditable performance when allowance is made for the differences in dispersion technique used for the two methods.

1. Introduction.

Because of the variability of soil samples, there has been a tendency in recent years for soil workers to develop more rapid rather than more accurate methods of analysis, so that larger numbers of samples can be examined to give a better estimate of any particular soil property. This attitude is justified with respect to mechanical analysis, for the pipette method is a comparatively long process.

Bouyoucos (1927, 1937) has attempted to reduce the time for mechanical analysis by using a hydrometer for measuring the silt and clay fractions, and a rapid method of dispersion, which omits parts of the usual pretreatment. The original method was inaccurate and improvements have been made by Wintermeyer *et. al.* (1931) and Thoreen (1933). This method has been extensively adopted by engineers interested in soil mechanics and is also in use in many agricultural laboratories.

From the literature concerning the use of the hydrometer for measuring densities of soil suspensions, it is obvious that insufficient study has been made of the fundamental theory necessary for a clear appreciation of the difficulties involved. In this paper it is proposed to discuss the theory of hydrometers when used in suspensions and also the errors involved, and further, to study the possibilities of reducing these errors to a minimum by means of suitable hydrometer design.

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2. Problems of Adaptation.

It is apparent that the use of a hydrometer for measuring densities of suspensions will create many problems which do not exist when they are used in homogeneous solutions. The main problem is the interpretation of the measured density, for which two things are necessary :—

(*a*) The density must be converted to express the percentage of soil in suspension.

(*b*) The particle size to which this measurement of density refers must be determined.

(i) *Conversion of Density to Percentage of Soil in Suspension.*

If soil of density ρ_s is dispersed in water of density ρ_w then

$$\Phi = m + \rho_w - \frac{m\rho_w}{\rho_s} \tag{1}$$

$$m = \frac{\Phi - \rho_w}{1 - \dfrac{\rho_w}{\rho_s}} \tag{2}$$

where m is the mass of soil in unit volume of the suspension of density Φ after any given settling time at any depth. Further, if M is the mass of soil originally dispersed in a volume Q of suspension, the percentage of soil remaining in suspension at that time and depth is P, then

$$P = \frac{mQ}{M} \cdot 100 \tag{3}$$

(ii) *Determination of the Particle Size to Which the Measured Density Refers.*

The percentage of total soil in suspension refers to certain sizes of particles. The particles to which it refers are those smaller than the particles which can just travel the distance from the surface to that depth in the suspension at which the density has been measured, in the time between the start of settling and the measurement of the density. If this depth in the suspension which has the measured density can be determined, then the size of particle can be calculated from Stokes' Law ; but the determination of this depth is the main difficulty in adapting the hydrometer for mechanical analysis of soils.

Other problems of adaptation, such as bulb streamlining to prevent disturbance of the suspension, the displacement of the suspension on immersion of the hydrometer, and the problem of suspended material settling on the bulb, will be discussed in later sections.

3. Errors of the Hydrometer when used for Measuring the Density of Soil Suspensions.

(i) *Errors Associated with the Conversion of Density to Percentage of Soil in Suspension.*

(*a*) *Temperature Changes.*—To determine the correction to be applied to readings made at temperatures other than that for which the hydrometer was calibrated, equation (1) may be differentiated for Φ with respect to ρ_w, m and ρ_s being constant.

$$\frac{d\Phi}{d\rho_w} = 1 - \frac{m}{\rho_s}$$

ρ_s is not strictly constant at different temperatures, but the changes are so small that they can be neglected in this calculation, and so ρ_s is assumed to be a constant having a value of 2·61. When 50 g. of soil are made up to 1,000 cc. suspension (5 per cent. suspension), m may vary from 0·00 to 0·05 according to the percentage of the total soil in suspension. With m at its greatest value of 0·05, $\frac{d\Phi}{d\rho_w} = 0 \cdot 98$, and as m approaches 0, $\frac{d\Phi}{d\rho_w}$ approaches 1. This means that for practical purposes in this concentration of suspension, the change of density of suspension with temperature may be assumed to be the same as the change of density of water. From equation (1) it can be calculated, for a 5 per cent. suspension, that a change of density of 0·0003 corresponds to a change of 1 per cent. of the total soil in suspension, and so the curve for the change of density of water over the temperature range expected can be converted to positive or negative corrections of percentage of soil in suspension, to be applied to the hydrometer readings at temperatures other than that for which it was calibrated.

Another effect of temperature is due to the cubical expansion of the bulb, but this is such an extremely small factor for a glass bulb that it can be entirely neglected.

(*b*) *Variations in Density of Suspended Material.*—From equation (1), Φ may be differentiated with respect to ρ_s, ρ_w and m being constant.

$$\frac{d\Phi}{d\rho_s} = \frac{m\rho_w}{{\rho_s}^2} \text{ or } d\Phi = \frac{m\rho_w}{{\rho_s}^2} \times d\rho_s$$

As before, the maximum value for m is 0·05 in a 5 per cent. soil suspension, and the only variation of ρ_w is due to temperature, which for this particular purpose may be considered constant so that ρ_w has a value of 1. If we consider $d\rho_s$ to be a difference of 0·1 from the commonly assumed value of 2·61 for ρ_s, then

$$d\Phi = \frac{0 \cdot 05}{(2 \cdot 61)^2} \times 0 \cdot 1 = 0 \cdot 00074$$

This change of Φ is equivalent to a change of 2·5 per cent. of the total soil in suspension and, since the value for m used above corresponds to 100 per cent. of soil in suspension, the error due to changes of soil density is 2·5 per cent. of the actual reading for each change of 0·1 from the accepted value of 2·61 for ρ_s. This correction is negative when the soil density is less than the assumed value and vice versa.

For a large proportion of soils the assumed value for ρ_s proves to be satisfactory; but it must be remembered that the densities of various soils are different and that even the densities of the various fractions of the soil are different and may vary over a wide range in some cases. It is possible to correct these errors to some extent if the densities of the various soils are known, but even then, the main disability, the differences of density of the various fractions, still remains. These errors are probably the most serious defects of the hydrometer method for mechanical analysis of soils.

(ii) *Errors Associated with the Determination of the Depth in the Suspension at Which the Density is the Same as That Measured by the Hydrometer.*

When hydrometers are used for measuring densities of homogeneous liquids the whole of the submerged portion of the hydrometer is surrounded by liquid of the same density, but in soil suspensions the immersed portion of the hydrometer is surrounded by a system of varying densities.

The general equation for a hydrometer floating in a stable homogeneous medium is $M_h - V\rho$, where M_h is the mass of the hydrometer, V is the submerged volume of the hydrometer, and ρ the density of the medium. In the case of a hydrometer floating in a soil suspension, the equation of equilibrium at any particular time is

$$M_h = v_1\rho_1 + v_2\rho_2 + v_3\rho_3 + \ldots \text{ \&c.}$$

where $v_1 + v_2 + v_3 + \ldots$ &c. $= V$, the submerged volume of the hydrometer; v_1, v_2, v_3, &c., being the volumes of those parts of the hydrometer displacing portions of the suspension having densities ρ_1, ρ_2, ρ_3, &c., respectively. At a depth x in the suspension the density is ρ_x, the measured density, and the value $V\rho_x$ can be substituted for M_h to give the following equation

$$V\rho_x = v_1\rho_1 + v_2\rho_2 + v_3\rho_3 + \ldots \text{ \&c.} \qquad (4)$$

If the relation between the density in the suspension with depth is linear, then the depth x will coincide with the centre of volume of the hydrometer, and if the volume of the stem is small in relation to the volume of the bulb it can be assumed that the depth x coincides with the centre of volume of the bulb.

Although Puri and Puri (1939) on experimental evidence maintain that under most normal conditions the relation is linear, it cannot be guaranteed, and in fact, it is doubtful whether the relationship is ever truly linear but mostly only somewhere near it.

For non-linear density-depth relationships there will be changes of the position of depth x in relation to the centre of volume which may be important, particularly for the larger particle sizes in which range the non-linear relationships are more likely to occur. These changes can best be minimized by reducing the vertical distribution of the volume of the bulb in relation to the length of stem, i.e., by making the bulb as short as possible.

(iii) *Errors due to Practical Difficulties.*

The accumulation of material settling on the upper surface of the hydrometer presents a disability which can be partially overcome by leaving the hydrometer in the suspension only for the shortest possible time. The placing in the suspension and subsequent removal of the hydrometer for each reading introduces the problem of disturbance of the suspension. This disturbance takes two forms, firstly owing to the movement of the hydrometer bulb through the suspension, and secondly, by virtue of the displacement of the suspension.

These errors are not insuperable and can be overcome by suitable hydrometer design.

4. The Design of a Suitable Hydrometer.

There are certain errors of a hydrometer when used for the mechanical analysis of soils which cannot be overcome by design, namely those due to changes of temperature, and the density of the soil. The error due to temperature can be corrected, but that due to variations in density between soil fractions will always present a source of error. All other errors which have been discussed can be corrected or at least reduced to a practical minimum by suitable hydrometer design.

(i) *Bulb Shape.*

The factors influencing the design of a suitable bulb shape are conflicting in many respects, and the best that can be done is to make some compromise, taking into consideration each factor according to its relative importance.

(*a*) The bulb must be short since errors due to non-linear density-depth relationships can be reduced to a negligible factor for any bulb shape by this means. On the other hand, for adequate streamlining a relatively long thin bulb would be the best.

(*b*) It is obvious that some shape combining the two features must be used, and possibly the best shape is a streamlined double cone.

(*c*) A steep angle of slope is desirable for the top portion of the bulb to prevent excessive collection of settling material.

(*d*) Although the bulb must have a relatively small volume in relation to the volume of suspension, so as to cause little displacement, it must have a reasonable volume so that the stem diameter can be of practicable size.

(ii) *Stem Design in Relation to the Bulb.*

The relation between stem volume and bulb volume for any hydrometer determines its range. For a hydrometer floating in a uniform liquid

$$\rho_1 (V + v) = \rho_2 V \text{ or } \rho_2 = \rho_1\left(\frac{v}{V} + 1\right) \qquad (5)$$

Where V is the submerged volume of the hydrometer when reading ρ_2, ρ_2 and ρ_1 are the densities corresponding to the lowest and highest graduation marks respectively, and v is the volume of the stem between the ρ_2 and ρ_1 marks.

This means that the range of the hydrometer depends on the ratio $\frac{v}{V}$, and so with small values for $\frac{v}{V}$ there is a small range. However, for a given value of v the sensitivity can be made as great as practicable by reducing the diameter of the stem.

When a 5 per cent. soil suspension is used for mechanical analysis there are only small differences of density for changes of the amounts of soil in suspension, the whole range only extending from about 1·00 to 1·03 g. per cc. If these values are substituted in equation (5) for ρ_1 and ρ_2 respectively, the value for $\frac{v}{V}$ is found to be 0·03. If a maximum value of $\frac{v}{V}$ of 0.01 be used, then for equal length of stem the range of the hydrometer is reduced to one-third but the sensitivity is increased three times; further, a value

of 0·01 reduces the volume of the stem to such a small proportion of the bulb volume that it has little effect on the position of the centre of volume of the hydrometer at different depths of immersion. Another possible error is reduced to a negligible factor by having the value $\frac{v}{V}$ equal to 0·01; the error being that, when the hydrometer is floating in a suspension, the bulb and stem are surrounded by different average densities, conditions different from those in which it was standardized.

Since a value of 0·01 for $\frac{v}{V}$ is to be used, it is necessary to use poises to increase the range of the hydrometer. These poises can be slipped over the stem and allowed to submerge with the hydrometer or be placed on a small hook or platform on the unsubmerged portion of the stem. If the poises are submerged with the hydrometer there is a possibility of slight errors due to the change of the effective weights of the poises according to the change of density of the suspension in which they are submerged. However, in a later design these poises have been placed on a platform at the top of the stem, since it was found that they tended to collect settling material on the top of the bulb.

5. The Test Hydrometer.

Results obtained with this hydrometer will serve to show what can be expected from a hydrometer which has some of the main features of good design, namely a short bulb and a low value for $\frac{v}{V}$.

(i) *Description and Technique.*

The hydrometer (see Plate 5, Fig. 1) has the following dimensions:

- Length of bulb = 7·0 cm.
- Length of stem = 17·5 cm.
- Maximum length of stem immersed = 6·0 cm.
- Diameter of stem = 1·6 mm.
- Volume of bulb = 14 cc. approx.
- Weight of poises 1, 2, and 3 were 0·1139, 0·1208, and 0·1328 g. respectively.

The poises were small copper rings which were slipped over the stem and allowed to submerge with the hydrometer. The hydrometer was calibrated by test in solutions of known density at 20°C. Densities were converted to percentages of soil material in suspension, assuming that the equivalent of 50 g. of oven-dry soil was dispersed to make 1,000 cc. of suspension. The method of dispersion was similar to that used for the Bouyoucos hydrometer, namely, stirring with an electrically driven propeller for 15 minutes using 10 cc. of N/2 sodium oxalate as dispersing agent.

The suspension was made up to 1,000 cc. in the cylinder and stirred for 1 minute with a brass paddle before being allowed to settle. Readings were taken at 2 minutes, 4 minutes, and 8 minutes after the start of settling for the determination of particles less than 0·02 mm. diameter, and at hourly intervals from 4 hours to 8 hours, if necessary, for the determination of the particles less than 0·002 mm. diameter. For most soils the latter determination was made within 6 hours.

Readings were made by using a wire frame attached to a metre rule fixed rigidly alongside the cylinder (see Plate 5, Fig. 2). The difference in height of the suspension surface and the tip of the stem was obtained, and from Fig. 1 the percentage of soil in suspension was read off according to the poises used. Correction for temperature was applied and 0·7 deducted as a correction for the presence of sodium oxalate. From another series of graphs in which length of stem above the liquid surface was plotted against the logarithm of the settling velocity for various times of settling, the log settling velocity of the particles measured for any reading could be obtained..

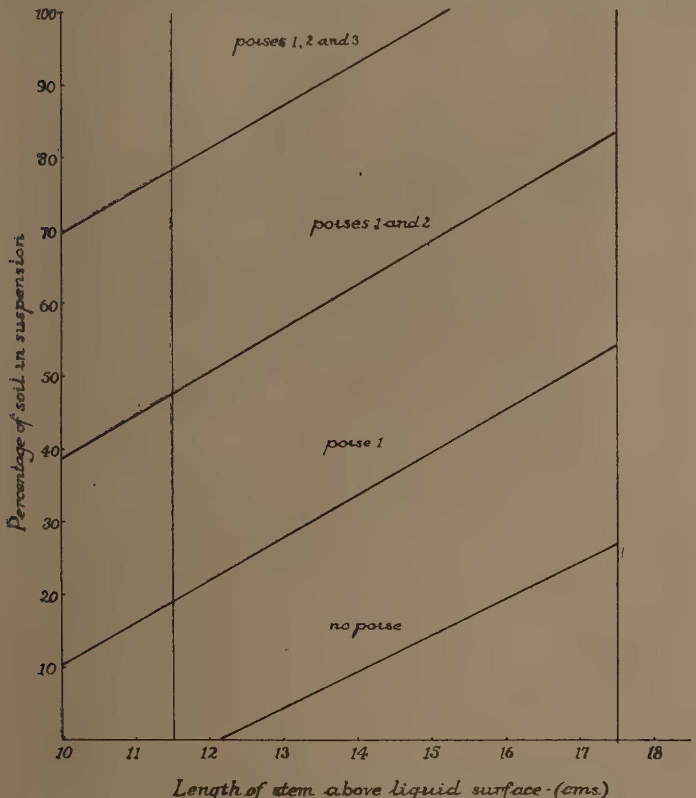

Fig. 1.—Graph showing method of converting length of stem to percentage soil in suspension.

Knowing the percentages of particles in suspension having less than the determined log settling velocities, summation curves may be plotted and percentages of particles having less than $\bar{2}{\cdot}54$ and $\bar{4}{\cdot}54$ log settling velocities may be read off. At 20°C, these log settling velocities correspond to particles of density 2·61 having diameters 0·02 and 0·002 mm. respectively, but if the mean temperature during the settling period is other than 20°C., other log settling velocities must be used to correspond with particles having those diameters. These are given in Table 1 for various temperatures of settling.

TABLE 1.—SHOWING LOG SETTLING VELOCITIES (IN CM. PER SECOND) CORRESPONDING TO PARTICLES OF DIAMETER 0·02 AND 0.002 MM. RESPECTIVELY FOR VARIOUS TEMPERATURES OF SETTLING (PARTICLE DENSITY 2·61).

Temp. (° *C.*).	< 0·02 mm.	< 0·002 mm.
10	$\bar{2}\cdot42$	$\bar{4}\cdot42$
15	$\bar{2}\cdot49$	$\bar{4}\cdot49$
20	$\bar{2}\cdot54$	$\bar{4}\cdot54$
25	$\bar{2}\cdot59$	$\bar{4}\cdot59$
30	$\bar{2}\cdot64$	$\bar{4}\cdot64$

(ii) *Results and Discussion.*

The results for silt and clay (< 0·02 mm. diameter) and clay (< 0.002 mm. diameter) for a number of soils have been obtained with the test hydrometer and compared with results obtained by the standard pipette method for mechanical analysis. These are given in Table 2.

The best way to treat these comparative results is by expressing the difference from the pipette result as a percentage of the hydrometer reading. The mean divergence of hydrometer readings from pipette readings is then found to be 4·5 per cent for the silt plus clay fraction and 6·2 per cent. for the clay fraction. When allowances are made for positive and negative errors the means are found to be + 2 per cent. and — 2 per cent. for the silt plus clay and clay readings respectively.

The mean of all errors irrespective of sign is about 5 per cent., which compares favorably with a set of Thoreen's results (1933) treated similarly, which showed a mean error of 11 per cent. for all readings over the same range.

This performance is creditable considering the differences in dispersion and also that the hydrometer is not well streamlined. However, the shortness of the bulb and the small value for $\frac{v}{V}$ are the two main features of good design, and although other refinements can be made it is thought that they will not alter the performance to any extent.

6. The Value and Limitations of the Hydrometer Method.

The hydrometer method for the mechanical analysis of soils is essentially a rapid method and is only used along with a rapid method of dispersion. This is one of its limitations, for all soils cannot be properly dispersed without full pretreatment, and so its use is limited to certain types. Soils containing large amounts of calcium carbonate, organic matter, or soluble salts cannot be analysed with the hydrometer because of the difficulty of dispersing them without adequate pretreatment. Even if they could be dispersed, the variation of density of the material in suspension from the assumed figure 2·61 would cause errors. The errors of the hydrometer which cannot be overcome by design preclude the use of the hydrometer with a long method of pretreatment and dispersion, since it does not save much time when used in such a way.

TABLE 2.—COMPARISON OF RESULTS OBTAINED WITH TEST HYDROMETER AND THOSE OBTAINED BY STANDARD PIPETTE METHOD.*

Soil No.	Locality.		Silt and Clay (< 0·02 mm.).				Clay (< 0·002 mm.).			
			Hydro-meter.	Pipette.	Differ-ence.	Diff. as per cent. of Hydro-meter Reading.	Hydro-meter.	Pipette.	Differ-ence.	Diff. as per cent. of Hydro-meter Reading.
3496	Waite Institute	S.A.	48·6	48·9	− 0·3	0·6	15·4	17·6	− 2·2	14·3
4357	Mount Barker	S.A.	36·1	34·5	+ 1·6	4·4	15·9	16·0	− 0·1	0·6
4537A	Curlwaa	N.S.W.	50·5	49·0	+ 1·5	3·0	33·3	33·3	..	..
2392	Bungunyah	N.S.W.	21·7	20·5	+ 1·2	5·5	15·3	15·5	− 0·2	1·3
2416	Dismal Swamp	S.A.	32·5	35·1	− 2·6	8·0	30·3	32·4	− 2·1	7·0
4543	Curlwaa	N.S.W.	61·2	59·8	+ 1·4	2·3	39·3	42·4	− 3·1	7·9
1927	Kuitpo	S.A.	42·3	39·1	+ 3·2	7·6	12·4	12·0	+ 0·4	3·3
2024	Kuitpo	S.A.	65·6	62·0	+ 3·6	5·5	30·6	30·8	− 0·2	0·7
2405	Goodnight	N.S.W.	12·3	12·8	− 0·5	4·1	10·0	10·9	− 0·9	9·0
4616	Pomona	N.S.W.	9·8	10·3	− 0·5	5·1	7·6	8·4	− 0·8	10·6
2837	Cobdogla	S.A.	44·6	40·3	+ 4·3	9·6	29·6	35·0	− 5·4	18·3
3205	Cobdogla	S.A.	42·5	42·6	− 0·1	0·2	35·4	34·2	+ 1·2	3·4
2892	Cobdogla	S.A.	41·2	41·8	− 0·6	1·5	31·1	31·0	+ 0·1	3·2
2736	Berri	S.A.	37·8	37·7	+ 0·1	0·3	29·5	32·8	− 3·3	11·2
2738	Berri	S.A.	24·5	25·3	− 0·8	3·3	17·4	16·8	+ 0·6	3·4
2118	Cadell	S.A.	8·1	6·7	+ 1·4	17·3	5·4	4·5	+ 0·9	16·7
2119	Cadell	S.A.	38·1	38·2	− 0·1	0·3	33·5	33·4	− 0·1	0·3
2359	King Island	Tas.	30·5	32·0	− 1·5	4·9	5·4	4·6	+ 0·8	14·8
2363	King Island	Tas.	37·8	38·1	− 0·3	0·8	17·2	18·2	− 1·0	5·8
3315	Lyrup	S.A.	49·7	49·1	+ 0·6	1·2	35·2	34·7	+ 0·5	1·4
6051	Red Cliffs	Vic.	22·9	23·2	− 0·3	1·3	14·9	15·6	− 0·7	4·7
4022	Denmark	W.A.	43·6	39·9	+ 3·7	8·5	33·0	35·4	− 2·4	7·3
4407	Denmark	W.A.	77·6	71·5	+ 6·1	7·9	61·2	60·6	+ 0·6	1·0
2567	Laffer	S.A.	63·0	60·5	+ 2·5	4·0	60·0	58·1	+ 1·9	3·2

* Pipette results were obtained from the records of the Soils Division, Council for Scientific and Industrial Research. The method of analysis included peroxide and acid treatment and dispersion using NaOH for most soils but for some of the soils having lower serial numbers NH_4OH was used as the dispersing agent.

Although, in general, results obtained with a hydrometer, after rapid dispersion of the soil, agree fairly well with those obtained by the pipette method, it appears certain that a high degree of reliability can never be attained.

The value of the hydrometer is mainly its rapidity along with a reasonable degree of accuracy. It has been shown that a suitably designed hydrometer can reduce many of the errors to a practical minimum; the remaining errors in most cases have little meaning, and if soil workers are prepared to accept errors of up to 10 per cent. on occasions, then the hydrometer is a valuable instrument which enables many more analyses to be made in a shorter time than when the pipette method is used.

7. Acknowledgments.

The author wishes to express his appreciation of the advice and criticism given by Dr. T. J. Marshall and to Mr. V. A. Stephen and Mr. A. D. Cocks who were responsible for the manufacture of the test hydrometer and for the photography respectively.

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NOTES.

The Late Dr. Alexander McTaggart (1883-1944).

On May 16, 1944, the death occurred in Sydney, following a short illness, of Dr. A. McTaggart, Principal Plant Introduction Officer in the Division of Plant Industry.

Born in New Zealand in 1883, the late Dr. McTaggart spent some years in the Department of Agriculture there before proceeding to the Ontario Agricultural College, Guelph, Canada, where he took his Bachelor of Science degree in 1912. This was followed by an M.Sc. (Agric.) degree at Cornell University in 1913, after which he returned to New Zealand, and held the position of agriculturist in the Dominion Department of Agriculture until 1919. His Ph.D. was obtained at Cornell in 1921, and after teaching soil technology and carrying out soil surveys there for some time, he was appointed Assistant Professor of Agronomy at Macdonald College, McGill University, a position which he held until joining the Council.

Appointed in 1929 to organize and take charge of plant introduction work in the newly-established Division, Dr. McTaggart brought with him a wide and varied background of knowledge on plant problems. During his fourteen years, he was responsible for introducing and testing more than 8,000 varieties of economic plants from all parts of the world, many of which have proved of value in peace or in war. Results with these plants have been reported in several contributions in the Council's journal and in Pamphlet No. 114, while another line of work was reflected in the preparation of Bulletin No. 99: " A Survey of the Pastures of Australia."

Dr. McTaggart was liked and respected by those who knew him for his qualities of sterling integrity, while he had, too, a rich strain of geographical romanticism which made the introduction of plants from far-off lands a matter of real and vital interest to him. His personal qualities found expression in kindly visiting the sick in hospital, in devotion to the Presbyterian Church and its work, and in Freemasonry in Canberra. His death at the early age of 61 removed one of the foundation members of the Division of Plant Industry, and one whose loss will be greatly felt.

Retirement of Mr. G. Lightfoot from Secretaryship.

Mr. G. Lightfoot retired from the position of Secretary of the Council at the end of June. He has now been co-opted as a member of the Council and will continue to assist it in a part-time capacity.

Mr. Lightfoot graduated from the University of Cambridge with first-class honours in the Mechanical Science Tripos, and later was called to the Bar, Middle Temple. He was the first senior officer appointed to the forerunner of the Council, the Advisory Council of Science and Industry, in 1916, and has been Secretary of the present Council ever since its formation in 1926. He was sent to Europe and America in 1916 to gather information in connexion with the setting up of the Advisory Council, and again in 1937 concerning the establishment of the Information Section, and in connexion with national standards.

Mr. Lightfoot has been succeeded as Secretary by Mr. G. A. Cook, who has been Assistant Secretary of the Council since 1927 and Officer-in-Charge of its Information Section since 1938.

Bag-Stack Fumigation of Wheat.

A simple method of fumigating wheat stacks has recenty been evolved, and the results obtained in large-scale trials are so promising that it seems the problem of controlling weevil in bag-stacks is solved. The same treatment will also kill rodents present in the stacks.

The method is extremely simple. Sheets of treated cotton fabric, which are practically airtight, are draped from top to bottom of the stack walls, leakage at the base being largely eliminated by laying bags of wheat on the bottom of the fabric, which trails on the ground. Liquid carbon bisulphide is then poured over the top of the stack, the dosage used being 1 gallon per 1,000 cubic feet of space. Hessian curtains are then unrolled over the top of the stack to reduce the loss of fumigant by diffusion.

There is no limit to the amount of wheat which can be fumigated at one time, and stacks containing 90,000 bushels have already been treated. The cost is less than a farthing a bushel.

The evolution of this technique was dependent upon experiments carried out over a long period by Messrs. F. Wilson and F. J. Gay of the Council. They discovered two unsuspected facts. First, that the fumigant, when applied on the top of the stack, would effectively penetrate throughout it. Secondly, that, given an airtight cover on the walls but not over the top of the stack, the rate of leakage of the fumigant was sufficiently slow to permit an excellent kill of weevil. Under these circumstances, the kill is not complete in the top few layers of bags, but as weevil infestation is usually restricted to the lower part of a stack, this limitation has little importance.

What is new in this method of stack fumigation is neither the use of airtight enclosures for fumigation nor of carbon bisulphide against wheat weevil, but the discovery and utilisation of these two facts. These have made it possible to overcome the difficulties presented to fumigation by the structural characteristics of bag-stack storage at depots and sidings, and have made bag-stack fumigation cheap and straight-forward instead of expensive and practically impossible.

The basic requirements for successful stack fumigation were laid down by Messrs. Wilson and Gay, and the practical application of their recommendations was carried out by Mr. C. W. Anderson of the Australian Wheat Board.

Fundamental Scientific Research*

I do not propose to expound here my own views on the conflict of opinions concerning the calling of science. But I would like strenuously to oppose the view that there are superior and inferior forms of scientific activity according to whether there is or is not a practical or humane end in view. I want to break down the distinction between what is called pure and applied research, believing that they are essentially one, in that, whatever may be the stated objective, they are pursued by the same method and with the same permutations and combinations of observation, theory, and experiment.

* Extracts from an address by Sir Edward Appleton, F.R.S., given to the Chamber of Commerce, Manchester, England, on April 20, 1944.

Nor do I think it very profitable to attempt to decide, as people have tried to do, which is the more important, a great discovery in pure science or a great discovery in applied science. But within the present century, owing to the impact of many scientific discoveries in our practical life, the general public has become so accustomed to the enjoyment of the fruits of science that there is a great danger lest it should regard the scientist as a servant whose task is solely to produce a succession of discoveries of immediate use to industry or directly to the individual member of the community. I believe that this exclusive concentration on the practical products of science in the public mind has to a large extent been fostered by events during the war when almost the whole of our scientific effort has necessarily been directed to investigations of short-term practical utility.

The main theme of my talk, then, this morning, is to be the wisdom of ensuring that there shall continue to be in this country many active research groups whose scientific work shall be that of free inquiry and the extension of man's knowledge of nature, unconcerned whether the final results are to be of practical use to humanity or not. I hope to show you that this is, indeed, one of the surest ways to a harvest of practical usefulness.

The matter was well put many years ago by Professor A. W. Hofmann, under whom the famous Perkins was working when he discovered the first aniline dye. Hofmann, in one of his addresses once wrote:—

> "Whenever one of your chemical friends, full of enthusiasm, exhibits and explains to you his newly-discovered compound, you will not cool his noble ardour by asking him that most terrible of all questions, What is its use? Will your compound bleach or dye? Will it shave? May it be used as a substitute for leather? Let him go quietly on with his work. The dye, the leather will make their appearance in due time. Let him, I repeat, perform his task. Let him indulge in the pursuit of truth—pure and simple—for the sake of truth."

But I would like to add a postscript to those words of Hofmann's, for it illustrates my second point, and that is, that although our young chemical discoverer should be encouraged to go on with his work with the objective as stated by Hofmann, I think it is equally important that there should be some other, more practical, man eager to test whether the new compound *will* bleach or dye. In other words, I regard it as essential that our applied scientists should keep themselves constantly in touch with the development of new knowledge, in order that the gap between discovery and its application should be bridged as quickly as possible.

I want to say a few words about the way fundamental research is carried out and about the conditions which seem to conduce to its successful prosecution. But the first thing to be said is that it is quite impossible to generalize about such matters, for important discoveries have been made in so many different ways. Chance often plays an important part, but the success really follows from a combination of chance and the prepared mind. Generally, I would say that fundamental scientific work flourishes most abundantly in an atmosphere of freedom, though I have known many a success follow from a young man's being persuaded, if not actually ordered, by his professor to leave a tempting side road and return to the main road on which he had embarked in the

first instance. Sometimes people work best in teams, and such types of organization are often essential for attacking certain types of problems. Sometimes, on the other hand, people work best singly. We must recognize these differences and allow for them.

I now turn to the subject of the organziation of fundamental research and the provision for it. I think it cannot be disputed that we must look to our universities for the main body of our fundamental research. There the easy contact and intercourse between workers in different fields can readily take place. A university atmosphere also gives that sense of freedom which so many of our best workers find essential to their best work. But experimental work nowadays usually costs money. Gone are the days when "sealing wax and string," according to the old Cambridge formula, will suffice. It is for this reason that grants for apparatus and assistance are given by Government Departments to university workers whose work is deemed to merit support. We must, I think, recognize in this connexion the importance of the exceptional man in the field of scientific research, the man with originality and imagination. It is far more important that he should be supplied with the facilities he needs and allowed, if he happens to work in that way, to inspire his team of juniors, than that a number of other people should be encouraged to continue more pedestrian investigations.

But I also believe that industrial research organizations and the research departments of Government should contribute their share to the general body of fundamental knowledge. Many big and enlightened industrial concerns regard it as a good investment.

I also believe it to be the function of the three chief civilian research organizations of Government—the Agricultural Research Council, the Department of Scientific and Industrial Research, and the Medical Research Council—to pursue fundamental research in fields which are ultimately likely to be of practical benefit to the general community. In considering research, we should, in particular, note the change in the function of Government in becoming less negative and more positive. In Graham Wallas's famous phrase, it "has come to be engaged not merely in preventing wrong things from being done, but in bringing it about that right things shall be done." In other words, its operation has ceased to be concerned solely with the safeguarding of rights and liberties and the prevention of crimes and abuses. It is now charged, in addition, with the active improvement of the welfare of the citizens of the country, and certain aspects of such improvement need scientific knowledge, some of which is available and only needs interpretation, and some of which has yet to be acquired.

I confidently believe that there is now a general awakening on the part of both Government and British industry to the importance of scientific research and the need for its extension and application. There will, I feel sure, be large post-war developments in industrial research and technology, but I want them to be sustained by an adequate volume of fundamental research. If the tree is to continue to bear fruit, we must ensure that there is healthy growth in its roots.

Recent Publications of the Council.

Since the last issue of this *Journal*, the following publications of the Council have been issued:—

Bulletin No. 175.—"The Recovery of Inter-block Information in Quasi-Factorial Designs with Incomplete Data. 2. Lattice Squares," by E. A. Cornish, M.Sc., B.Agr.Sc.

This is the second of a series of papers concerned with the recovery of information in quasi-factorial designs that have incomplete data. The paper describes an approximate method for dealing with lattice squares and discusses the effect of the approximations on the estimation of the adjusted treatment effects and their errors and the analysis of variance.

Bulletin No. 176.—"The Analysis of Cubic Lattice Designs in Varietal Trials," by I. F. Phipps, M.Sc., B.Agr.Sc., Ph.D., A. T. Pugsley, B.Agr.Sc., S. R. Hockley, and E. A. Cornish, M.Sc., B.Agr.Sc.

This Bulletin describes in detail the procedure to be adopted for recovering inter-block information in cubic lattice designs, and the computations which are required for this full analysis are illustrated by a numerical example.

Bulletin No. 178.—"Food Composition Tables," compiled by H. R. Marston and Mary C. Dawbarn.

This Bulletin is a revision and an enlargement of Pamphlet 107, which was assembled hurriedly to meet the requirements of the Department of the Army. As the matter was urgent, it was not possible to include in the Pamphlet references to the sources of information from which the tables and annotations were compiled, but a bibliography of 475 references has been included in the present Bulletin.

Tables are given showing the protein, fat, carbohydrate, mineral, and vitamin contents of foodstuffs and the calories which they provide. The effects of cooking on the vitamin contents of foods are tabulated and the influence of different methods of preservation and storing is also shown. Dietary standards of the food requirements of man are discussed.

Forthcoming Publications of the Council.

At the present time, the following future publications of the Council are in the press:—

Bulletin No. 177.—"A Soil Map of Autralia," by J. A. Prescott, D.Sc., A.A.C.I.

Bulletin No. 179.—"Lubrication between the Piston Rings and Cylinder Wall of a Running Engine," by J. S. Courtney-Pratt, B.E., and G. K. Tudor, B.E.

Bulletin No. 180.—"Studies on Deglutition in Sheep. 1.—Observations on the Course Taken by Liquids through the Stomach of the Sheep at Various Ages from Birth to Maturity," by R. H. Watson, D.Agr.Sc. "2.—Observations on the Influence of Copper Salts on the Course Taken by Liquids into the Stomach of the Sheep," by R. H. Watson, D.Agr.Sc., and I. G. Jarrett, B.Sc.

Bulletin No. 181.—"Sheep Blowfly Investigations. The Attractiveness of Sheep for *Lucilia cuprina*," by I. M. Mackerras, M.B., Ch.M., B.Sc., and M. J. Mackerras, M.B., M.Sc.

Bulletin No. 182.—"The Effectiveness of Various Mineral Dusts for the Control of Grain Pests," by J. S. Fitzgerald, M.Sc., Ph.D., A.A.C.I.

Bulletin No. 183.—"Experimental Determination of the Influence of the Red-legged Earth Mite (*Halotydeus destructor*) on a Subterranean Clover Pasture in Western Australia," by K. R. Norris, M.Sc.

PLATE 1.

Double-compartment Pot Cultures for Studies in Plant Nutrition.
(See page 144.)

Showing the development of lucerne roots in water containing, from left to right (See Footnote, Table 1) :—

1. Nil.
2. Calcium sulphate and calcium phosphate (solution 3).
3. Calcium phosphate (solution 1).
4. Calcium sulphate (solution 2).

PLATE 2.

Double-compartment Pot Cultures. (See page 144.)

Showing the effects of phosphate on lucerne in podsolised soil (top photograph) and river sand (bottom photograph). (See Footnote, Table 1.)

Soil.	*Sand.*	*Treatment*
10	11	Solution 4 in lower compartment.
12	13	Phosphate added to the sand and soil in the upper compartment: solution 4 in the lower compartment.
16	4	No phosphate added to the sand or soil: calcium sulphate and calcium phosphate in the lower compartment (solution 3).
14	18	Phosphate added to solution 4 in the lower compartment (solution 5).

PLATE 3.

An Automatic Irrigator Actuated by a Soil-Moisture Tensiometer.
(See page 151.)

General view of an automatic irrigator in use.

PLATE 4.

The Protection of Split-ring Connectors Against Corrosion.
(See page 162.)

Photograph of five $2\frac{1}{2}''$ rings and sections of four.

PLATE 5.

The Use of the Hydrometer for the Mechanical Analysis of Soils.
(See page 197.)

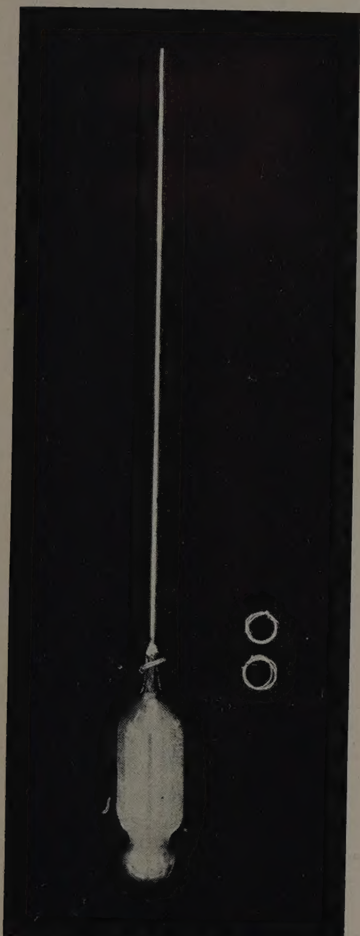

FIG. 1.—The test hydrometer.

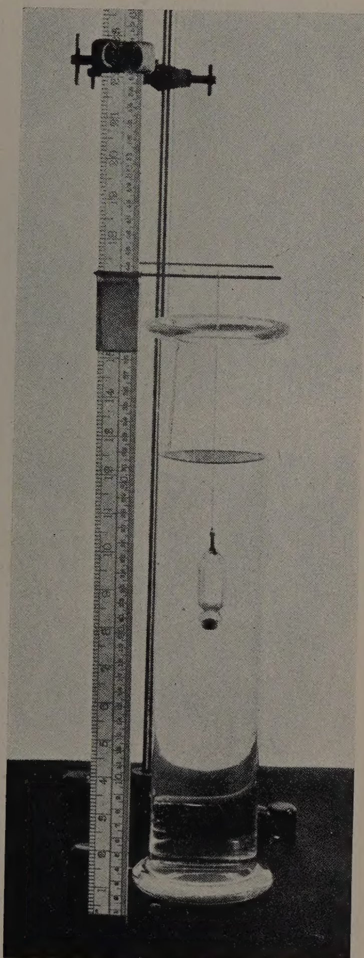

FIG. 2.—The test hydrometer in position in a solution.

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